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Space Shuttle Program

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Phase B Final Report
Expendable Second Stage
Reusable Space Shuttle Booster

Volume I. Executive Summary

Contract NAS9-10960, Exhibit B
DRL MSFC-DRL-221, DRL Line Item 6
DRD MA-078-U2
SD 71-140-1
25 June 1971

Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

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REUSABLE SPACE SHUTTLE BOOSTER

Volume I
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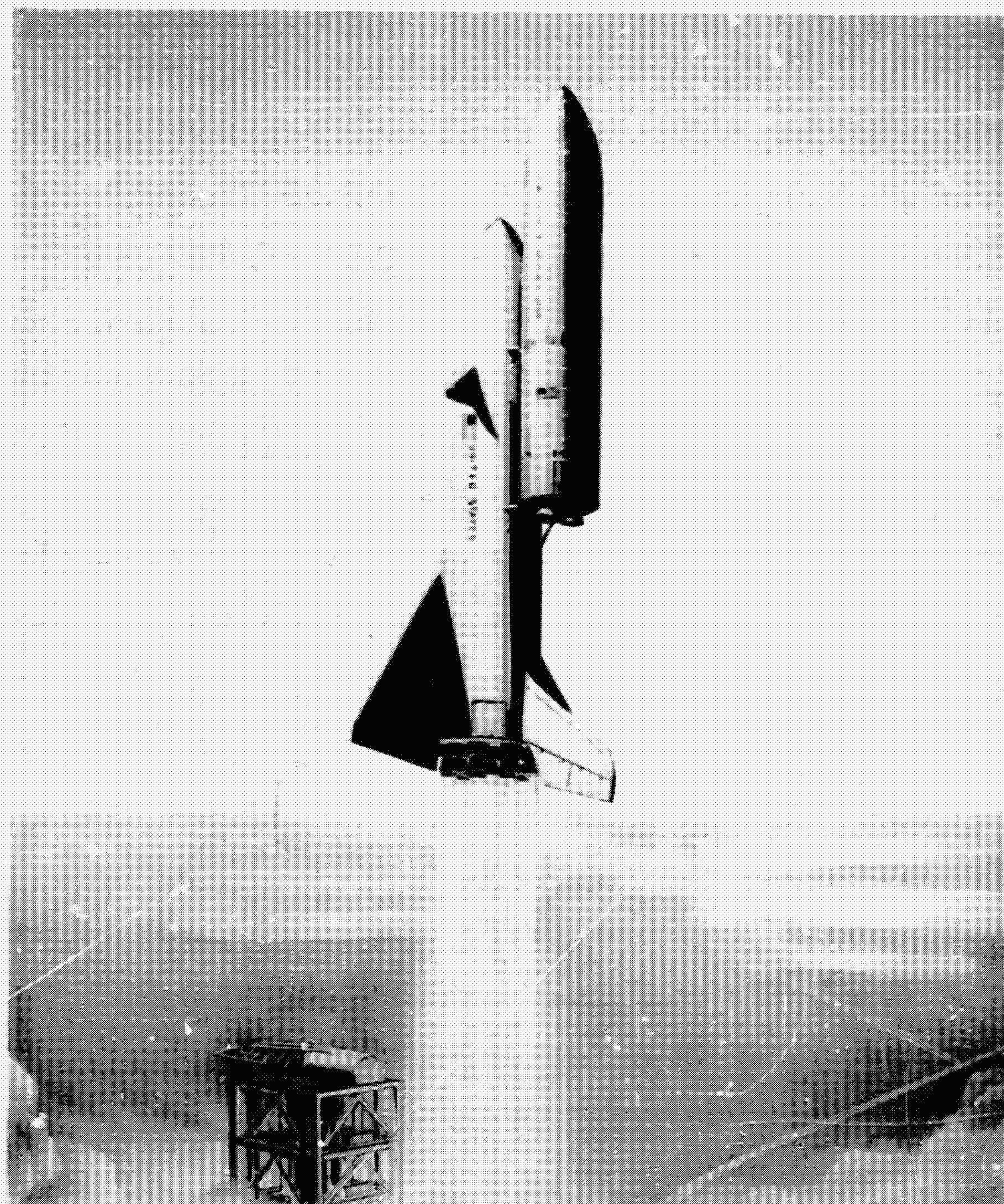
Approved by

for B. Hello
Vice President and General Manager
Space Shuttle Program

Space Division • North American Rockwell 12214 LAKEWOOD BOULEVARD • DOWNEY, CALIFORNIA 90241



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PREFACE

This document is a summary presentation of the results of the Phase A/B Study for an Expendable Second Stage on a Reusable Space Shuttle Booster accomplished by the North American Rockwell Corporation (NR) under Contract NAS9-10960, Exhibit B, to the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. All technical direction for this supplement to the Space Shuttle Phase B Definition Study has been provided by the NASA Marshall Space Flight Center, Huntsville, Alabama. The study was conducted from September 14, 1970 through June 1971 by the Space Division of NR, supported by the Convair Aerospace Division of General Dynamics Corporation as a major subcontractor. In addition to this shuttle program study, supplementary support on the expendable second stage (ESS) concept has been provided under the Saturn S-II Launch Vehicle NASA Contract, NAS7-200, to provide data on Saturn S-II modifications required to make the stage a candidate ESS, and on defining the interfaces with other elements of the complete system. The International Business Machines Corporation, Huntsville, Alabama, provided guidance, navigation, and control data which have been incorporated into the report. This effort was carried out under separate contract with NASA.

The study final report is presented in 12 volumes. They are this document, Volume I, Executive Summary; Volume II, Technical Summary, Books 1 through 3; Volume III, Wind Tunnel Test Data; Volume IV, Detail Mass Properties Data; Volume V, Operations and Resources; Volume VI, Interface Control Drawings; Volume VII, Preliminary Design Drawings; Volume VIII, Preliminary CEI Specifications - Part I; Volume IX, Preliminary System Specification; Volume X, Technology Requirements; Volume XI, Cost and Schedule Estimates; and Volume XII, Design Data Book.

The results of the Space Shuttle Phase B Definition Study provide a clear definition of a low-cost, reusable multipurpose space transportation system for the 1980's. Utilizing the reusable booster element of the space shuttle and an ESS derived from the Saturn S-II, the Phase A/B ESS study has established the definition of a system capable of economically placing payloads in earth orbit which are larger and heavier than can be carried in the shuttle orbiter cargo bay. NASA has identified three such representative payloads - a large space station, a nuclear stage, and a space tug (geosynchronous mission). The ESS/reusable shuttle booster system thus will be complementary to the space shuttle system and will provide the mission flexibility to permit the economical expansion of the overall space program of the 1980's, especially in the area of logistics supply of maximum payloads to low earth orbit.

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INTRODUCTION

Since the beginning of the national space flight program, the development of the capability to place significant payloads into space has been rapid. Space missions require the use of efficient, large rocket engines. The manned space flight goals required the construction of launch vehicles with very large thrust, made possible by employing rocket engines in clusters. The largest of these vehicles is the Saturn V, with a lift-off thrust of some 8 million pounds. The Saturn S-II, the second stage of Saturn V, produces more than a million pounds of thrust for about six minutes after separation from the booster stage. This translates into a capability to place some 200, 000 pounds of payload into low earth orbit. The delivery cost per pound of payload, however, has been substantially higher than is projected for the space shuttle system. The reduction of payload delivery cost is considered to be a key requirement, if expansion of space flight activities is to be accomplished in the future. The primary approach to meet this requirement is to design a system which provides for multi-reuse of the high-value elements of the system and, if necessary, to expend only those elements which cannot be economically recovered for reuse.

To derive a system which eventually will meet the low-cost payload delivery needs of the scientific, military, and commercial communities, during the past decade the Government has sponsored numerous studies to determine the feasibility of reusable vehicles to transport men and a variety of equipment between earth bases and selected space orbits.

The concept embodies design and operations resembling those for commercial aircraft, thus obviating the expenditure of a costly launch vehicle with each payload delivery. With this concept as a goal, a space shuttle system utilizing a reusable booster and orbiter that can transport persons and cargo to low earth orbit and return the crew, passengers, and cargo safely to earth is now being evaluated through a preliminary design and development study (Phase B). The shuttle system is being designed to handle payloads up to approximately 65, 000 pounds. The cargo bay into which these payloads must fit is cylindrical and is 60 feet long and 15 feet in diameter. Most of the total projected payload can be handled by the shuttle for the decade of the 1980's. In addition to the missions which can be satisfied with the shuttle payload capability, NASA has missions planned that require space vehicles to place payloads in excess of 100, 000 pounds in earth orbit. To satisfy this requirement, a cost-effective multimission space shuttle system with large lift capability is needed. Such a system would utilize a reusable shuttle booster and an expendable second stage (ESS). ESS would be complementary to the space shuttle system.

To evaluate the ESS concept, a two-phase study was authorized by NASA. Phase A, which ended in December 1970, concentrated on performance, configuration, and basic aerodynamic considerations. Basic trade studies were carried out on a relatively large number of configurations. At the conclusion of Phase A, the contractor proposed a single configuration. Phase B commenced on February 1, 1971, based on the recommended system. Whereas a large number of payload configurations were considered in the initial phase, Phase B was begun with specific emphasis on three representative payload configurations. The entire Phase B activity has been directed toward handling the three representative payload configurations in the most acceptable manner with the selected ESS and toward the design of the subsystems of the ESS.

The purpose of this volume is twofold: to delineate the ESS concept and system and to provide an overview of the system's relationship to the reusable space shuttle. Since the book constitutes only a summary of the ESS Phase B study, vehicle and mission descriptions are brief, and program elements such as facilities, manufacturing, and test (covered in other volumes of this report) are not treated. Detailed analyses, drawings, and engineering data pertaining to the several ESS systems and subsystems are included in Volume II, Technical Summary, SD 71-140-2.

This final report is organized in accordance with Contract NAS9-10960, DRL MSFC-DRL-221, Line Item Number 6, and DRD Number MA078-U2, dated August 28, 1970. The document is submitted by North American Rockwell through its Space Division and contains results of design, performance, and resource studies performed during the Phase B portion of the contract. The results of the Phase A study were reported in December 1970 in the Interim Final Report (Phase A only), SD 70-607. A summary of these results is included in this volume.

STUDY OBJECTIVES, REQUIREMENTS, AND APPROACH

To supplement the shuttle capability, a space shuttle system utilizing an expendable second stage with a reusable space shuttle booster has been under investigation for the past nine months of the Space Shuttle Phase B Definition Study. The prime objective of this supplemental study has been to determine the feasibility, cost-effectiveness, and preliminary design of such a system which is to be suitable for a wide variety of advanced space missions beginning in the last half of CY 1979.

The study was divided into two sequential phases: Phase A and Phase B. Phase A required analysis and definition of space shuttle systems with an optimized expendable second stage (a) utilizing existing hardware, (b) space shuttle 400,000-pound engines*, and (c) new hardware or (d) combination of existing and new hardware. Further, the definitions of systems with minimum modified S-II stages and minimum modified S-IVB stages were included.

The study depth was to be sufficient to permit a decision by NASA on whether to proceed with a particular approach or to eliminate all concepts from further consideration. To accomplish this objective, consideration was given to the following:

1. The defined payload spectrum (Phase A, Figure 1; Phase B, Figure 2).
2. The required operational characteristics.
3. Identification of any modifications and the extent of penalties (if any) in payload and performance required to optimize the reusable booster with the selected expendable second stage (but without incorporation into the Phase B Space Shuttle System Study).
4. Research, design, test and evaluation, production, and operational costs.
5. Identification of cost/performance/mission effectiveness.

The study requirements associated with these objectives are included both in the Statement of Work and in the Study Control Document. In the latter, data on the following are included: baseline system requirements, mission requirements, desired system characteristics, mass properties, cost control and design performance management system, payload

*The thrust level for Phase B was increased to 550,000 pounds at sea level.

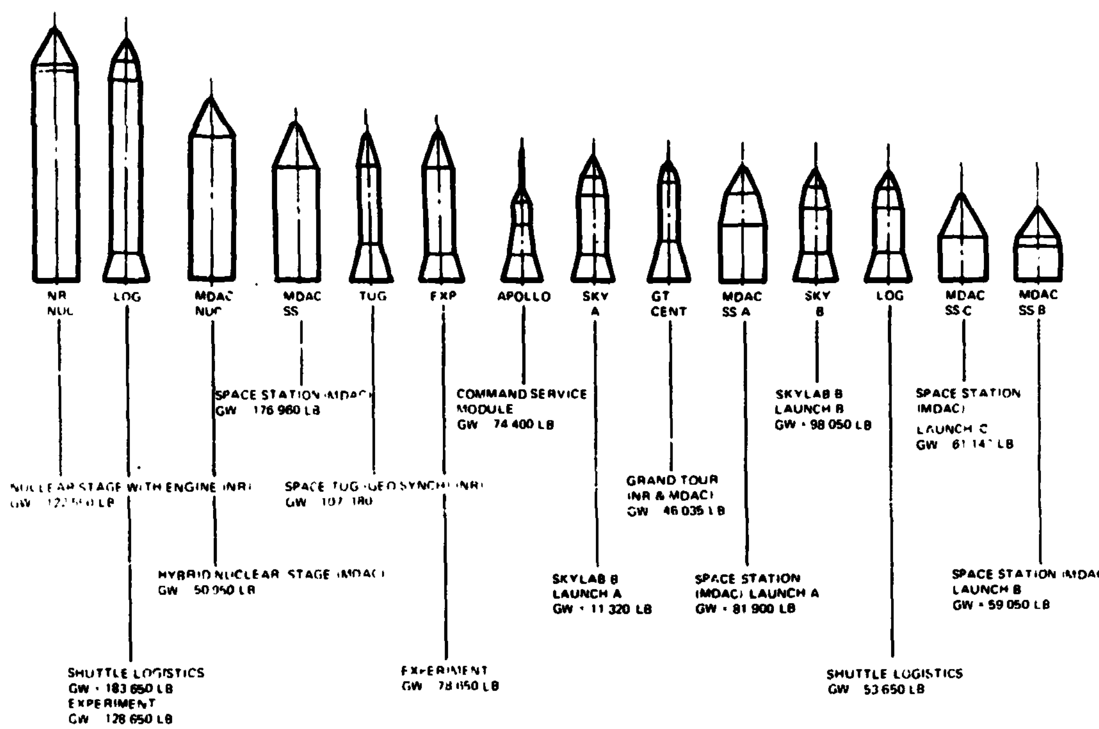


Figure 1. ESS Payloads—Phase A

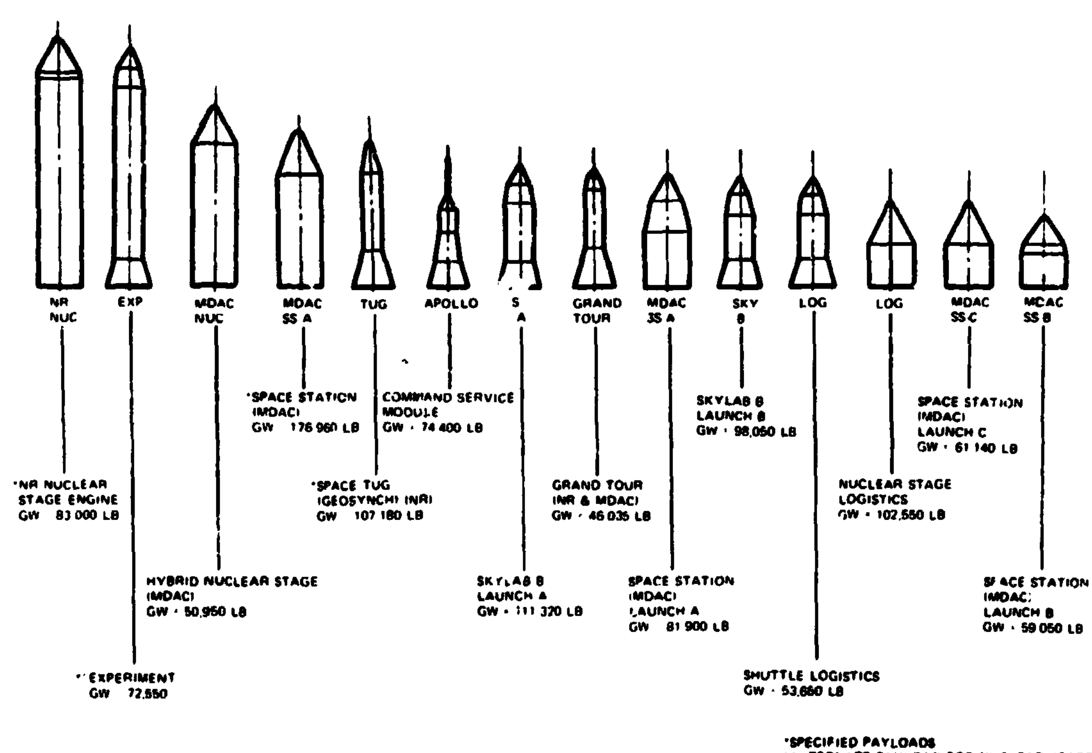


Figure 2. ESS Payloads—Phase B

configurations, and work breakdown structure. Variations from the baseline system requirements or desired system characteristics were subjected to evaluation by the contractor. In the event improvements in mission capability or reductions in cost could be shown, the contractor has recommended revisions.

Since study requirements are covered in detail in Volume II, Technical Summary, of this report, only a few will be discussed herein. System requirements related to mating an expendable second stage and payload combination on the space shuttle booster include: (1) basic shuttle operational capabilities must be maintained; and (2) the booster configuration used in this study must be current with Phase B shuttle progress, with booster definition limited to modification of the baseline developed in the shuttle Phase B contract activity. Also, the liquid propellant rocket engines for the initial study were designated as the J-2, the RL-10, and the space shuttle high-performance engine.

Mission requirements include (1) a design reference mission for the logistic supply of maximum payloads into the design reference orbit, and (2) a design reference orbit consisting of a 270-nautical-mile circular orbit, with a 55-degree inclination. The mission of the expendable second stage may last up to 24 hours.

Typical desired system characteristics include provision for deorbit capability for the expendable second stage. Also, all-azimuth launch capability from KSC/ETR with minimal checkout at the launch pad is desired. The desired system characteristics activity includes making the cost comparison of the ESS system (without payload cost), using the design reference mission (DRM).

The study approach may be summarized as follows: Phase A, Part I (Candidate Vehicle Sizing), approximately 40 configurations considered; Phase A, Part II (Gross Vehicle Definition), three configuration types selected for further consideration, followed by the recommendation to NASA of a single configuration; after NASA evaluation, Phase B preliminary design and definition of the selected system.

During the Phase B portion of this study, the technical approach leading to the selected system emphasized the use of the most up-to-date information on the shuttle baseline booster configuration along with an ESS which contained subsystems best meeting the requirements for the ESS missions and payloads. Early in the Phase B activity, the shuttle baseline booster was identified as a vehicle incorporating twelve 550,000-pound-thrust space shuttle engines. The selected ESS concept (short S-II stage with two space shuttle engines), combined with the booster, was quickly determined to have more than adequate payload performance to meet all the NASA-defined requirements (Figure 2). However, minimization of structural effect on the reusable booster is a requirement. Hence, primary attention was directed toward this goal, and the three specified payloads were analyzed to cover the anticipated payload spectrum requirements.

The basic approach was to create flight trajectories which would meet the requirements for each payload and still yield only minimal effects on the booster. To minimize booster effects, it is necessary to load the vehicle to the lowest loading possible. It was considered reasonable to trade payload margin for flight load reduction by flying "low-loads" trajectories. Such trajectories require the use of more propellant than a maximum-payload trajectory. The nominal (no-wind) trajectories that evolved permitted control and loads investigations to proceed, including wind effects. Also, since deorbit of the spent ESS structure is a requirement, along with the necessity for safing the ESS after reaching orbit, the requirement exists to minimize unused residual propellants, which otherwise would remain in the ESS if the propellant loading required for a heavy payload is associated with a large, bulky, but relatively lightweight payload. The technical approach adopted took these factors into account.

The ESS design approach relative to the several subsystems was balanced between the maximum use of existing qualified Saturn/Apollo subsystems and/or elements and selective use of shuttle-developed components which will perform similar functions. Also, growth potential was considered—such as the possibility of the ESS evolving into a chemical interorbital shuttle.

OPERATIONAL CONCEPT

This summary of the expendable second stage mission operations, illustrated in Figure 3, is based on performance data, design concepts, and mission requirements existing at the conclusion of the Phase B study. The presently defined system has inherent flexibility and can accommodate considerable variation within the limiting criteria now established.

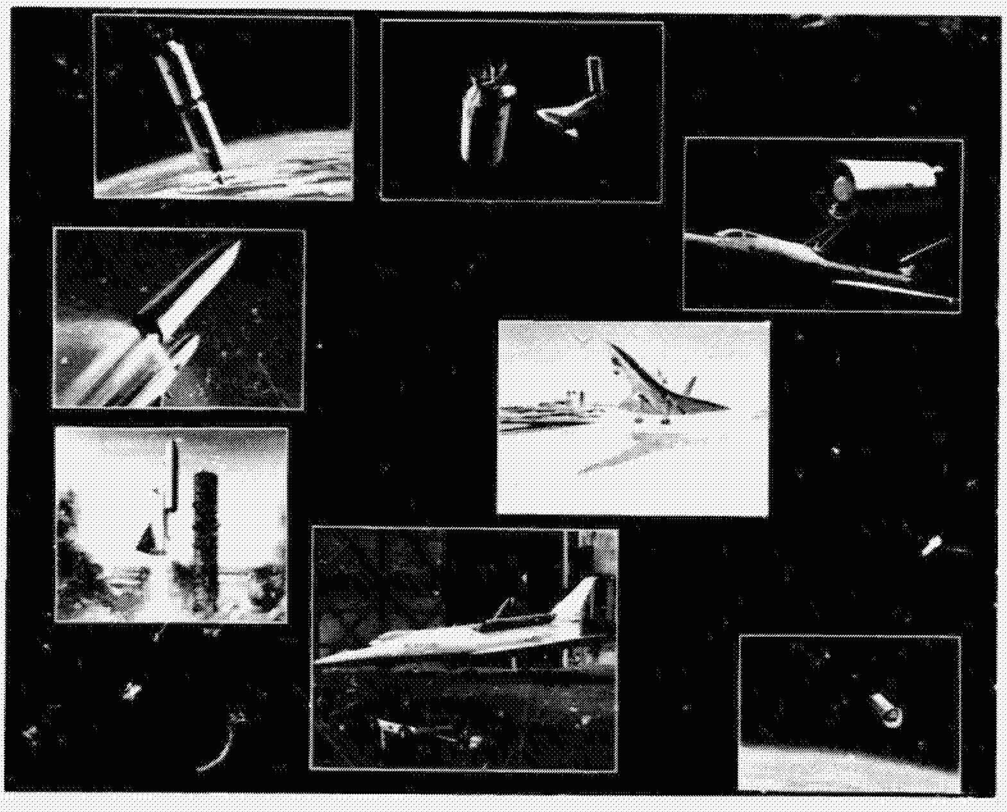


Figure 3. ESS Mission Operations

Major elements of the space shuttle system are the booster vehicle, the orbiter vehicle, and the launch operations and service complex. Acquisition of these three elements, insofar as the ESS mission is concerned, is considered to be a baseline program. Only the acquisition and operation of the ESS vehicle, its unique ground support equipment (GSE), and modifications or additions to both the reusable booster—including software for guidance and control—and the launch operations and service complex are factors to be evaluated.

The launch sequence begins with independent premate checkout of the separated booster and ESS vehicles in the assembly building. The selected payload, which may require fueling and monitoring, also is checked out.

Each vehicle, including the payload, is erected to the vertical launch position. The booster is mounted to the launch umbilical tower; the ESS is attached to the booster; the payload is mounted in tandem atop the ESS; and the mated vehicles are transported from the assembly building to the launch pad after the interfaces are checked out.

Following arrival at the pad, the various power, servicing, and checkout interfaces among the pad and vehicles are connected and checked, launch-readiness checkout is performed, and the launch countdown is commenced with loading of propellants. When loading is completed, the crew boards the booster vehicle for terminal countdown and launch.

The booster's 12 main engines are fired, and, within three minutes after liftoff, the combined vehicles achieve a comparatively level course at an altitude of 275,000 feet. In rapid sequence, the two rocket engines on the ESS are ignited, the booster engines are shut down, and separation of the two vehicles occurs. As the ESS accelerates toward orbit, the booster prepares for return to the launch site.

Assuming an entry attitude and descent trajectory that produce minimum aerodynamic heating, the booster descends unpowered for the next seven minutes to an altitude of approximately 20,000 feet. Twelve air-breathing turbofan engines are then deployed beneath the wing and started. At approximately 15,000 feet, the vehicle assumes a typical aircraft cruise mode under which it flies back to the base and lands on a conventional runway.

The ESS, meanwhile, continues to accelerate until an elliptical insertion orbit of 66 by 100 nautical miles is achieved. The two main engines are then shut down, and the two smaller orbit maneuvering engines are ignited to place the vehicle in the desired circular orbit. Depending on the mission, this orbit may be established at a nominal 100- to 270-nautical-mile altitude. Typical of missions in which the ESS would place payloads in a circular orbit of 100-nautical mile altitude and an inclination of 28.5 degrees are the space tug (geosynchronous mission) and the Grand Tour vehicle. An ESS mission which would require a 240-nautical mile orbit at 50-degree inclination are the Skylab B and the command-service modules (Skylab CM/Apollo SM).

ESS missions at 260 nautical miles and 31.5-degree inclination would include a nuclear stage (without engine), a hybrid nuclear stage (MDAC), and a nuclear stage logistics vehicle. Candidate payloads for the ESS at a

270-nautical mile circular orbit at 55-degree inclination include a space station (MDAC) as a single-launch configuration and/or a space station in a three-launch configuration. Other candidate payloads for this injection orbit include a shuttle logistics vehicle and experiment modules. The nuclear stage (without engine), the space tug (geosynchronous mission), and the space station single-launch configuration were specified by NASA as baseline payloads for the Phase B study to facilitate in-depth evaluation.

The baseline requirement for the ESS is a nonrendezvous mission, since the above missions do not, at least initially, require a rendezvous. Later, rendezvous with a passive target may become a requirement.

With reference to Figure 3, in the typical expendable second stage mission, the ESS will separate from the payload after achieving the desired low-earth orbit. It will remain in the near vicinity of the payload, but precautions will be taken to assure safe operation and to avoid recontact between the vehicles.

In concept, assuming a space station payload as shown, one mission option would be to launch the orbiter first to a relatively low orbit in the plane desired for the space station. This procedure would be desirable, since the orbiter is normally stocked with sufficient consumables to remain on orbit for up to seven days, and would make space station launch delays less critical than otherwise. Perhaps the next day the ESS/space station normally would be launched to its own designated orbit. The orbiter would be responsible for effecting rendezvous with the space station after the ESS had separated safely from the station. In this manner, the up-cargo activity associated with the orbiter flight could be accomplished well before the ESS had been in operation for 24 hours, the maximum currently provided.

After undocking from the space station, the orbiter effects a rendezvous and docking maneuver to link up with the passive ESS vehicle. The ESS has attitude-hold capability and a docking port on the aft skirt region of the structure. A hard-docking concept currently appears most promising for implementing recovery operations for high-value equipment on the ESS. The two space shuttle orbiter engines and selected avionics equipment are obvious candidates for retrieval and subsequent reuse.

To perform the equipment-retrieval operations, the orbiter/ESS combination is stabilized by the orbiter attitude control propulsion system, which consists of 29 small thrusters located at various points on the vehicle. Once the vehicle is stabilized, the cargo bay doors are opened and the cargo bay is made ready for receiving the ESS components.

Articulated manipulator arms are used by cargo-handling specialists to recover the components. The cargo specialists are located in the cargo-handling station aboard the orbiter, where they control the positioning and movement of the manipulator arms. Floodlights and television monitors installed on the arms ensure visibility throughout these operations. The ESS baseline configuration includes specific means for detaching the two space shuttle engines from the ESS thrust structure, and indicates handling points on the engines. Similarly, means for detaching selected avionics equipment are illustrated. Stowage of and securing these recovered valuable items within available space in the cargo bay appears feasible, and total down-cargo weight is within the capability of the orbiter.

After undocking of the orbiter from the ESS, with the ESS still retaining attitude control through a separate reduced-cost deorbit avionics package, each vehicle prepares to deorbit at an appropriate time in its orbit. The ESS will deorbit by utilizing its orbit maneuvering and attitude control propulsion subsystems. The deorbit trajectory is calculated to yield safe disposal over large ocean areas where shipping and other traffic is light. The footprint where some portions of the structure may impact is approximately 1500 nautical miles downrange and about 60 nautical miles wide.

The orbiter is maneuvered to a 100-nautical-mile orbit and rotated to a deorbit attitude. The remainder of the descent and landing sequence is identical with that of a normal orbiter flight. After removal of the recovered ESS elements from the cargo bay of the orbiter, these elements are put through a refurbishment cycle to place them in qualified condition for reuse.

Ground turnaround procedures for the reusable booster following an ESS mission are essentially the same as for a normal shuttle flight; that is, the elapsed time between landing and launch readiness is 14 calendar days in each case. The principal difference to prepare for an ESS flight is the need to remove the normal separation linkage from the booster and replace it with a heavier separation mechanism to accommodate the ESS-payload combination. This ESS-related structure is exchanged for an orbiter set following an ESS launch. This task is carried out in parallel with other maintenance activities, thus permitting normal flight operations to continue as scheduled.

STUDY PROGRAM

PHASE A/B ESS STUDY PLAN

Before the go-ahead date for the ESS study, a study plan (SD 70-404) was prepared. After go-ahead, the study plan was updated on October 13, 1970. This plan outlined all tasks required by the Statement of Work, time-phased as indicated in Figure 4. The basic Phase A plan can be noted as previously described. Phase ^ was concluded by publication of the Interim Final Report (Phase A only), SD 70-607, dated December 30, 1970, which can be consulted for more details of Phase A activities.

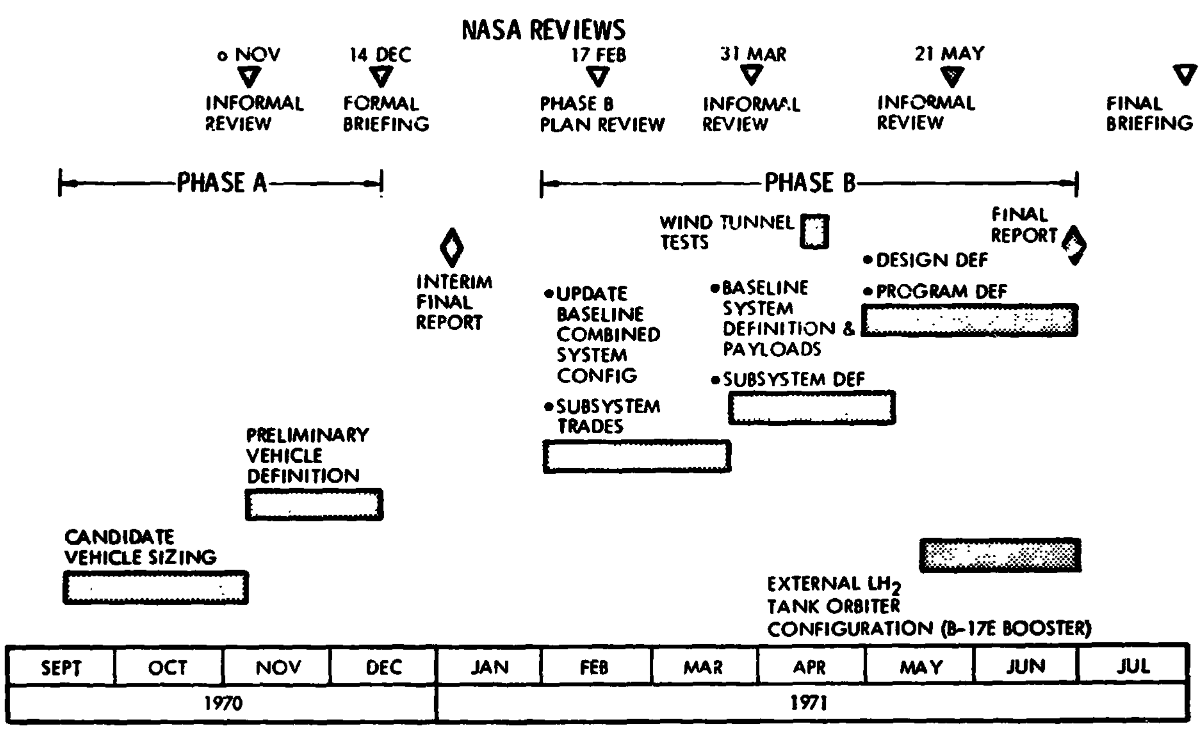


Figure 4. ESS Phase A/B Study Plan

The Phase B plan includes ESS subsystem trades, along with updating the baseline combined system configuration, baseline system and subsystem definition, and, finally, preliminary design and program definition for the selected system. Reviews by NASA at appropriate intervals are indicated. Also shown on the plan are reporting dates, wind tunnel tests, and the definition of impact of the selected ESS on the booster configuration which evolved in the External LH_2 Tank Orbiter Study (Space Shuttle Phase B Definition Study). On the latter, basic compatibility was determined, and is reported in Volume II, Technical Summary. Revisions to the NASA Study Control Document through May 5, 1971 have been incorporated into the study.

This final report covers primarily the Phase B portion of the study. Therefore, the study schedule for this phase (only) is shown in Figure 5.

SUMMARY - PHASE A ACTIVITIES

To determine the feasibility and cost-effectiveness of placing large payloads into orbit with an expendable second stage combined with the reusable shuttle booster, many candidate booster configurations were considered. In the Phase A studies, payload-delivery capabilities were determined for systems using the space shuttle reusable booster, a new expendable second stage, and derivatives of the S-II, S-IVB, and space shuttle orbiter. From the performance data of the candidate systems, the capabilities of these systems to perform the missions and deliver the payloads identified in the section on Study Objectives, Requirements, and Approach were defined. Performance characteristics and cost-effectiveness data of the candidate systems identified at study initiation were used to select the most promising concepts for a feasibility investigation and a more detailed evaluation.

The feasibility investigation was directed toward the following:

1. Establishment of the controllability of the integrated shuttle booster and ESS during the ascent phase of the mission.
2. Confirmation that modifications to the shuttle booster for use with the ESS would not preclude its use in the shuttle system.
3. Confirmation that structural loading conditions would not require major structural modification of the shuttle booster or Saturn stage derivatives.
4. Confirmation that systems would satisfy safety requirements defined for shuttle.

The detailed evaluation of selected systems led to the recommendation to perform a Phase B preliminary design study on a system using the most current space shuttle booster combined with an S-II derivative incorporating two shuttle main engines.

The Phase A study demonstrated concept feasibility and showed that the recommended system with a 167,000-pound payload-delivery capability would, on the basis of weight, place in design reference orbit 87 percent of

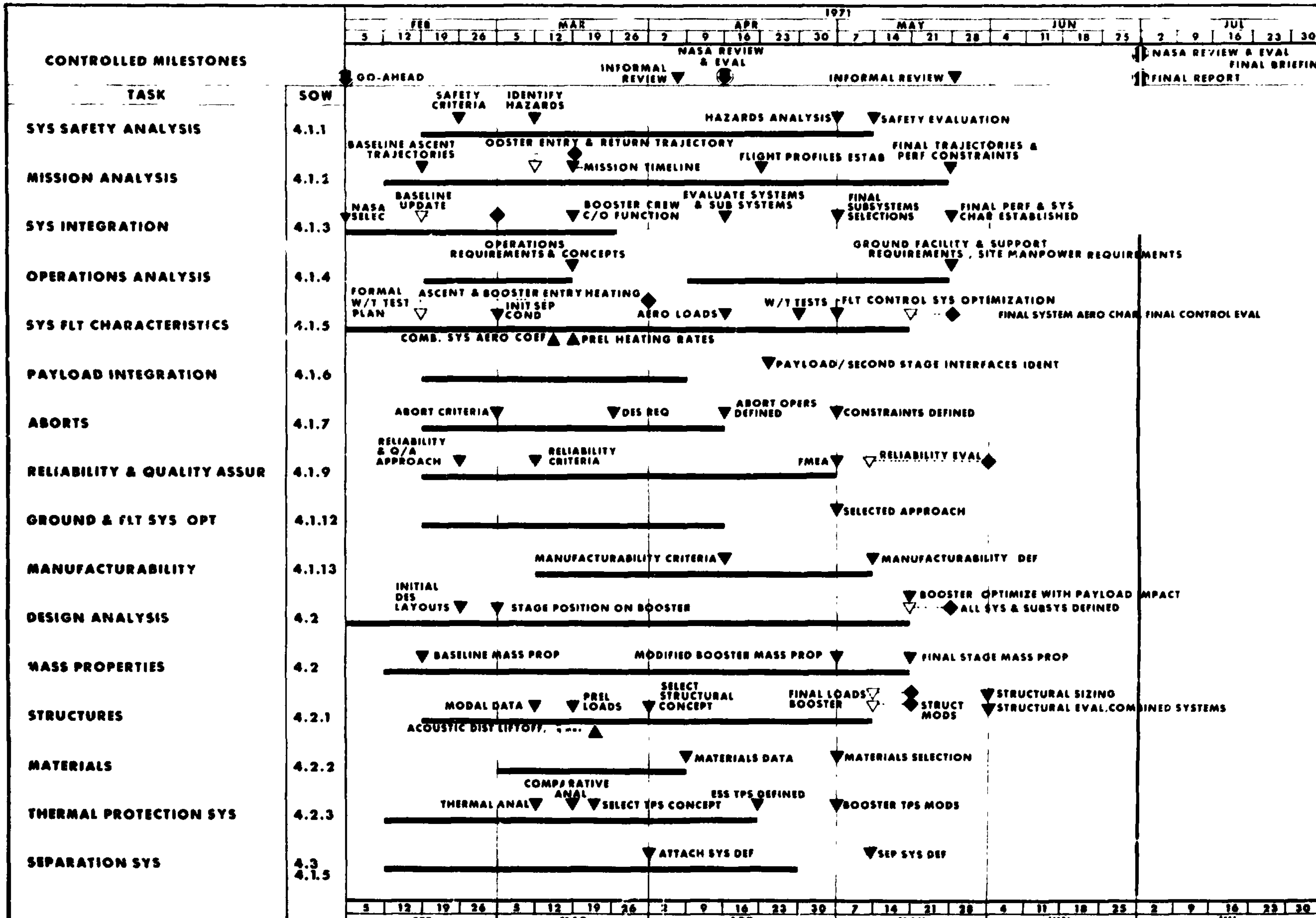


Figure 5. Phase B Study Schedule — E .S/Reusable Shuttle Booster (Sheet 1 of 2)

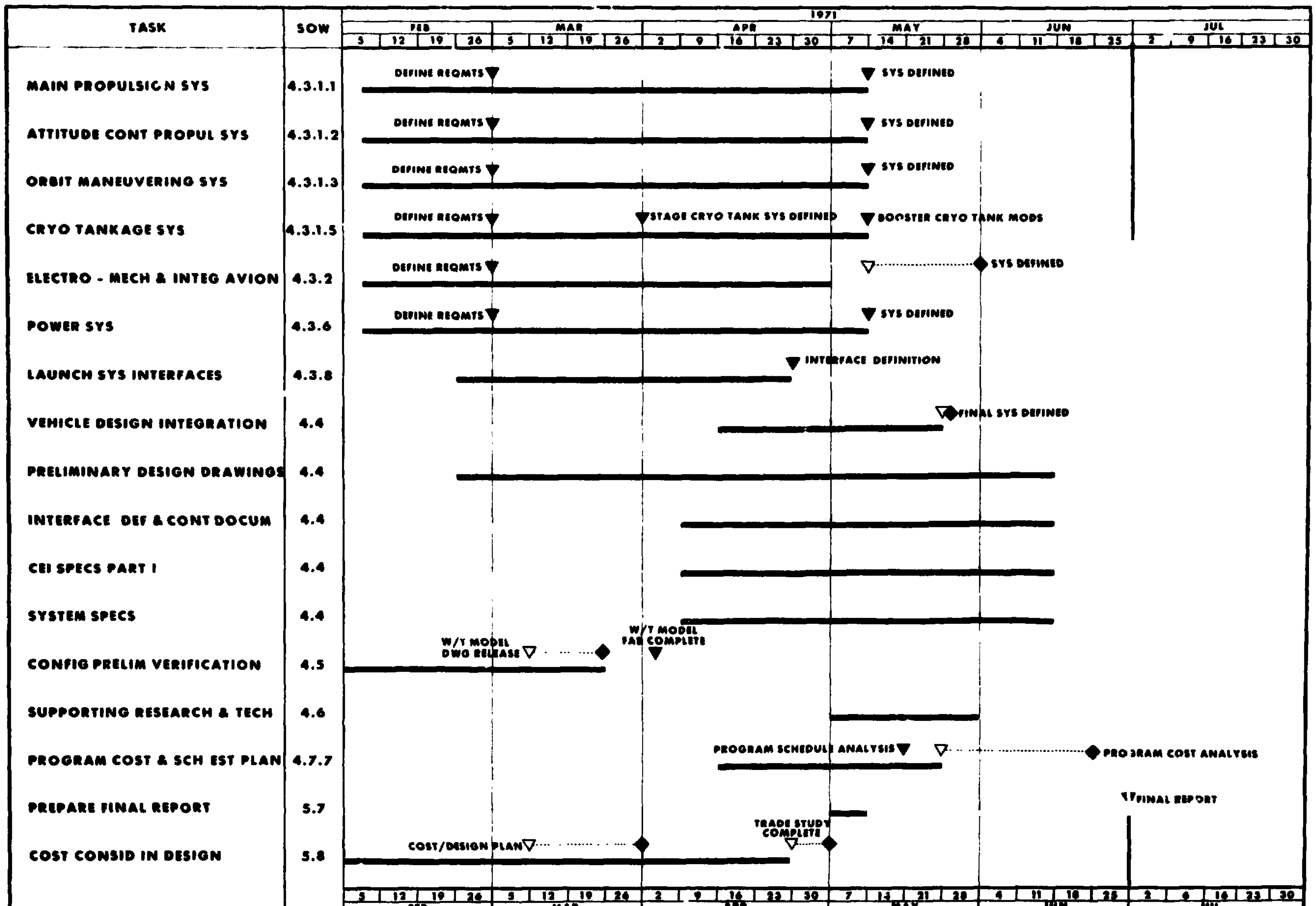


Figure 5. Phase B Study Schedule—ESS/Reusable Shuttle Booster (Sheet 2 of 2)

the candidate payloads. This system would be more cost-effective than current all-expendable hardware. The approach during the Phase A study always was to maintain the current shuttle booster baseline. The evolution of this baseline booster is described in Table 1.

At the time of the orientation meeting for this study (September 29, 1970), the baseline booster defined by the NR Space Shuttle Program was that for the low cross-range (LCR) orbiter. This baseline booster (Figure 6) featured 11 engines, had a gross weight of 2.86 million pounds, and carried a 675,000-pound orbiter. The attachment links shown in the figure are the current reverse-link concept; the attachment design loads were based on the 675,000-pound orbiter.

Using the 11-engine booster, an initial ESS payload matrix was defined at the orientation meeting, as indicated in Figure 7. Entries in parentheses were subject to variations or optimization. Figure 8 shows the matrix specifically considered during the first part of the study and presented at the November 6 informal review. Figure 9 indicates the mission profile used for performance calculations. Figure 10 shows orbiter-derivative performance for both the 11-engine and the 12-engine (3.15-million-pound) boosters. The shuttle axial load shown on these charts is equal to three times the applicable orbiter weight; hence, with an ESS-payload combination heavier than the orbiter, throttling below 3 g is required to permit the ESS loading to remain below the shuttle axial load limits. A performance comparison of the S-II derivative and ESS configuration is presented in Figure 11. Figure 12 shows how the payload can be increased by the use of a larger booster than the 11-engine version. Conservative payloads are shown, with initial estimates of ESS end-boost weights. An 8000-pound IU was used for the 33-foot-diameter S-II, a 5000-pound IU was used for the 21.7-foot-diameter S-IVB. For these cases, it was assumed that the reusable booster would land at a downrange site (such as Seymour-Johnson AFB), refuel, then fly back to KSC.

In order to obtain maximum payload performance, loading the ESS candidates to weights greater than the orbiter gross weight is necessary. Convair concluded that the increased attachment loads would affect the booster primary structure and thus increase the cost of the program. However, the overall assessment of whether the increased cost would be more than offset by a performance gain could not be made until later in Phase A. The cost-effectiveness analysis on November 6 showed that, for the S-II derivatives, a shortened S-II with two space shuttle engines

Table 1. Space Shuttle Boosters Used in Expendable Second Stage Study

	GD Number		
Item	B-8H*	B-8J	B-9T
Date	Oct 1970	Nov 1970	Dec 1970
Payload to DRM (lb)	25,000	25,000	25,000
Orbiter type	LCR**	HCR	HCR
Shuttle Gross Lift-off Weight (lb)	3,531,000	3,798,000	4,881,000
Booster gross weight (lb)	2,856,000	3,148,000	3,936,000
Orbiter gross weight (lb)	675,000	650,000	945,000
Booster engine number	11	12	12
SL thrust per engine (lb)	415,000	415,000	540,000
Flyback fuel	JP	JP	JP
Booster return to	N.C.	N.C.	KSC
Booster propellant weight (lb)	2,348,000	2,608,000	3,162,000

*Booster discussed in study orientation meeting at NASA MSFC, 29 September 1970

**LCR = low cross range, HCR = high cross range

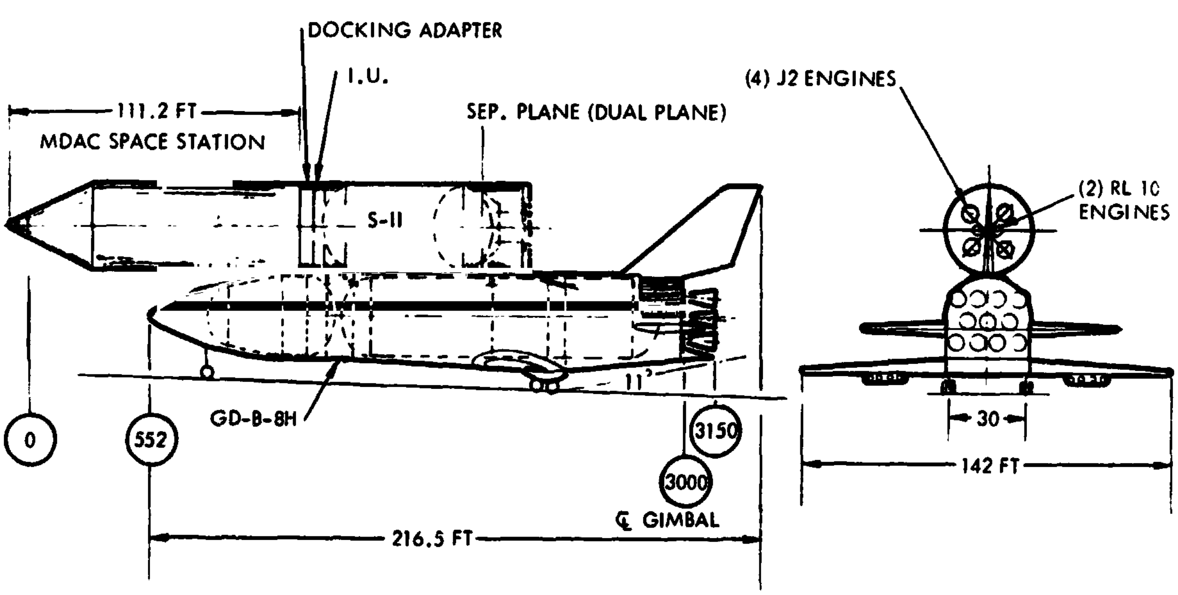
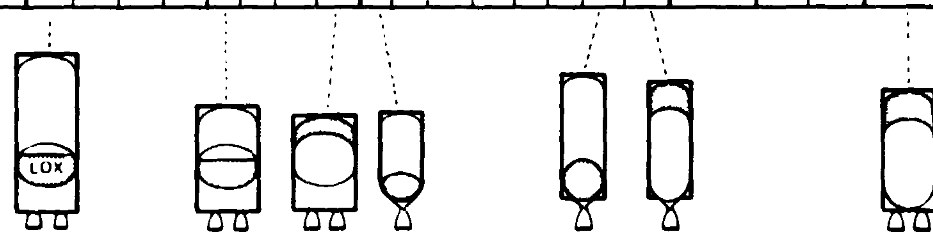


Figure 6. Minimum-Modification S-II/MDAC Space Station Configuration

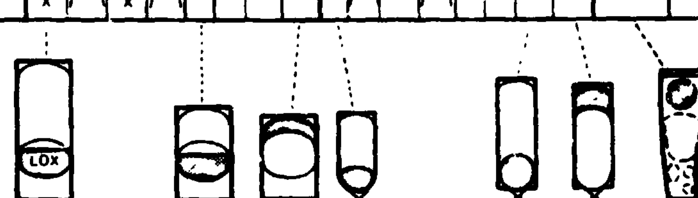
	DERIVATIVES OF EXISTING STAGES																NEW STAGES			
BASIC STAGE	S II								S IVB								ORBITER DERIV			ALL NEW
PHILOSOPHY	MIN MOD				OPTIMUM				MIN MOD				OPTIMUM				MIN MOD	RETAIN POWERPACK		
MS ENGINES	J 2		SHUTTLE		J 2		SHUTTLE		J 2		SHUTTLE		J 2		SHUTTLE		SHUTTLE	SHUTTLE		SHUTTLE
NUMBER	*(4)		(2)		(4)		(2)		1		1		1		1		2	2		(2)
PROPELLANT CAPACITY KLBS	970		970		(700)		(700)		230		230		(300)		(450)		(450)	(600)		(600)
DIAMETER INCHES	396		396		396		396		260		260		260		260		NA	(324)		(324)
ORBITAL MANEUVERING	(2 RL 10)		(2 RL 10)		(2RL 10)		(2 RL 10)		(APS)		(APS)		(APS)		(APS)		2 RL 10	2 RL 10		(2 RL 10)
LOX FORWARD?	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	YES	NO	YES	(YES)
PAYLOADS																				
SKYLAB							X								X				X	X
SPACE STATION	X		X		X	X	X	X	X		X		X	X	X	X	X	X	X	X
RNS			X		X		X				X		X		X		X		X	X
TUG							X								X				X	X
GRAND TOUR SC							X								X				X	X
APOLLO CSM							X								X				X	X



*( ) DENOTES ITEM SUBJECT TO OPTIMIZATION

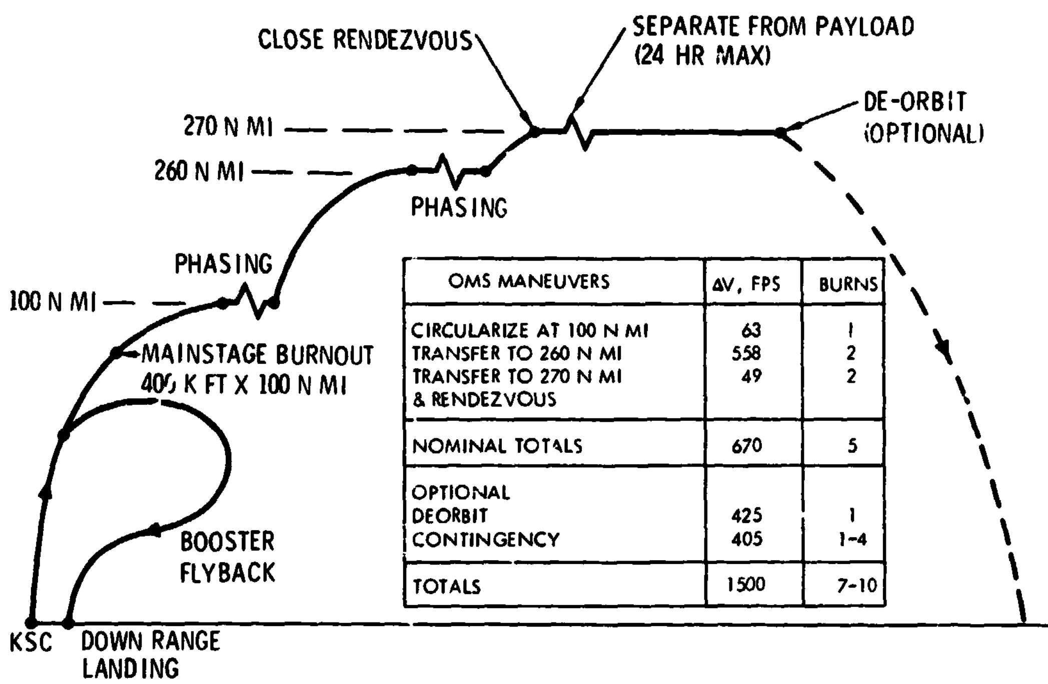
Figure 7. Initial ESS-Payload Matrix

	DERIVATIVES OF EXISTING STAGES																NEW STAGES	
BASIC STAGE	S-II								S IVB								ORBITER DERIV	
PHILOSOPHY	MIN MOD				OPTIMUM				MIN MOD				OPTIMUM				MIN MOD	RETAIN POWERPACK
MS ENGINES	J-2		SHUTTLE		J-2		SHUTTLE		J 2		SHUTTLE		J 2		SHUTTLE		SHUTTLE	SHUTTLE
NUMBER	*(4)		(2)		(4)		(2)		1		1		1		1		2	2
PROPELLANT CAPACITY, KLBS	970		970		(700)		(700)		230		230		(300)		(450)		(450)	(600)
DIAMETER, INCHES	396		396		396		396		260		260		260		260		NA	(324)
ORBITAL MANEUVERING	(2 RL-10)		(2 RL-10)		(2RL-10)		(2 RL 10)		(APS)		(APS)		(APS)		(APS)		2 RL 10	2 RL 10
LOX FORWARD?	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	YES	YES
PAYLOADS																		
SKYLAB	X		X															
SPACE STATION	X		X		X	X	X	X	X		X		X	X	X	X	X	X
RNS	X		X															
TUG	X		X															
GRAND TOUR SC	X		X															
APOLLO CSM	X		X															



*( ) DENOTES ITEM SUBJECT TO OPTIMIZATION
SUBJECT TO OPTIMIZATION

Figure 8. ESS-Payload Matrix—November 6, 1970



OMS MANEUVERS	ΔV, FPS	BURNS
CIRCULARIZE AT 100 N MI TRANSFER TO 260 N MI TRANSFER TO 270 N MI & RENDEZVOUS	63 558 49	1 2 2
NOMINAL TOTALS	670	5
OPTIONAL DEORBIT CONTINGENCY	 425 405	 1 1-4
TOTALS	1500	7-10

Figure 9. Representative Mission Profile

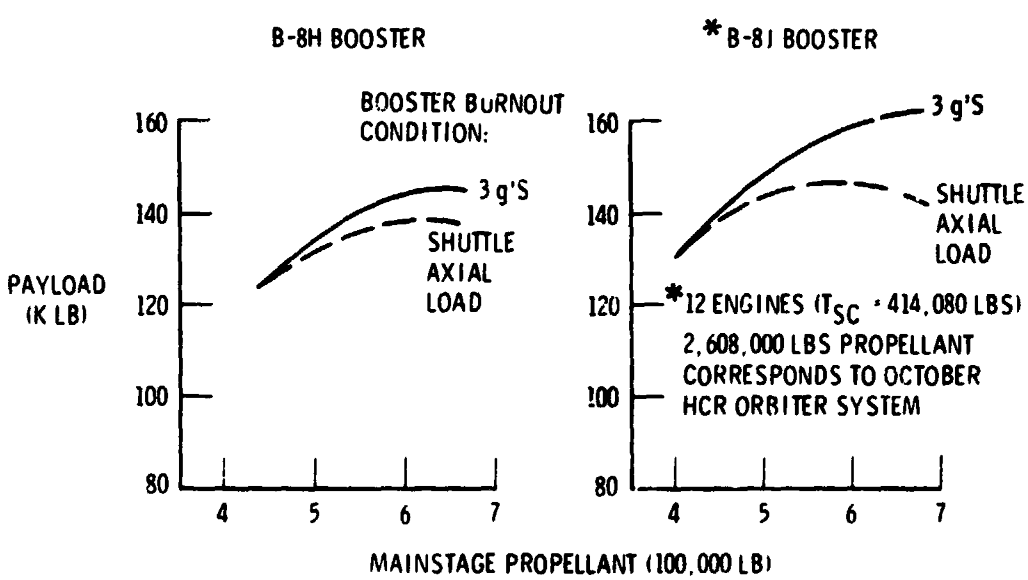


Figure 10. Performance of Orbiter Derivatives for ESS Mission— 33-Foot-Diameter Payload

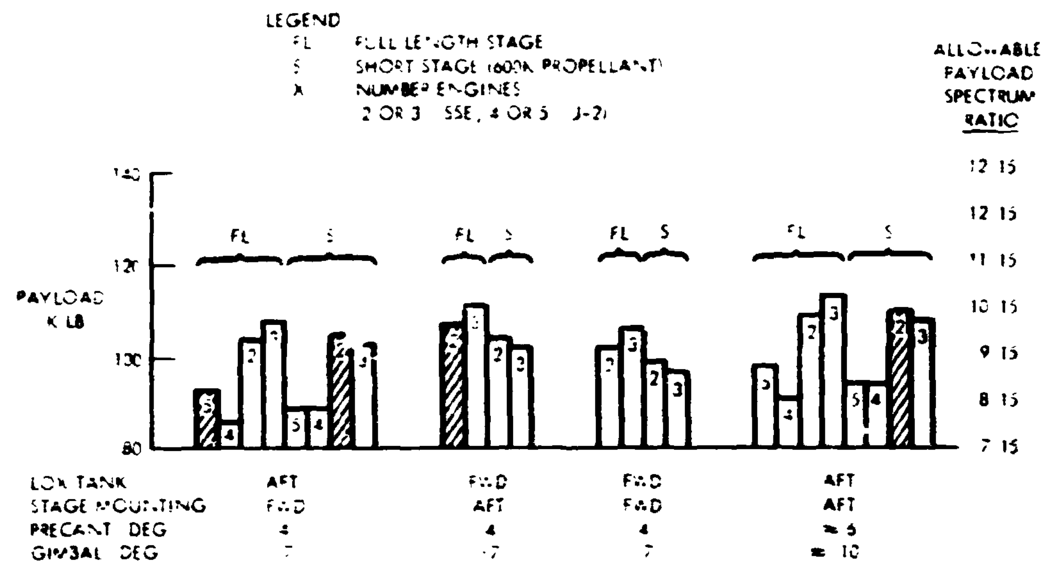


Figure 11. Comparison of S-II-Derived ESS Configurations—B-8H Booster

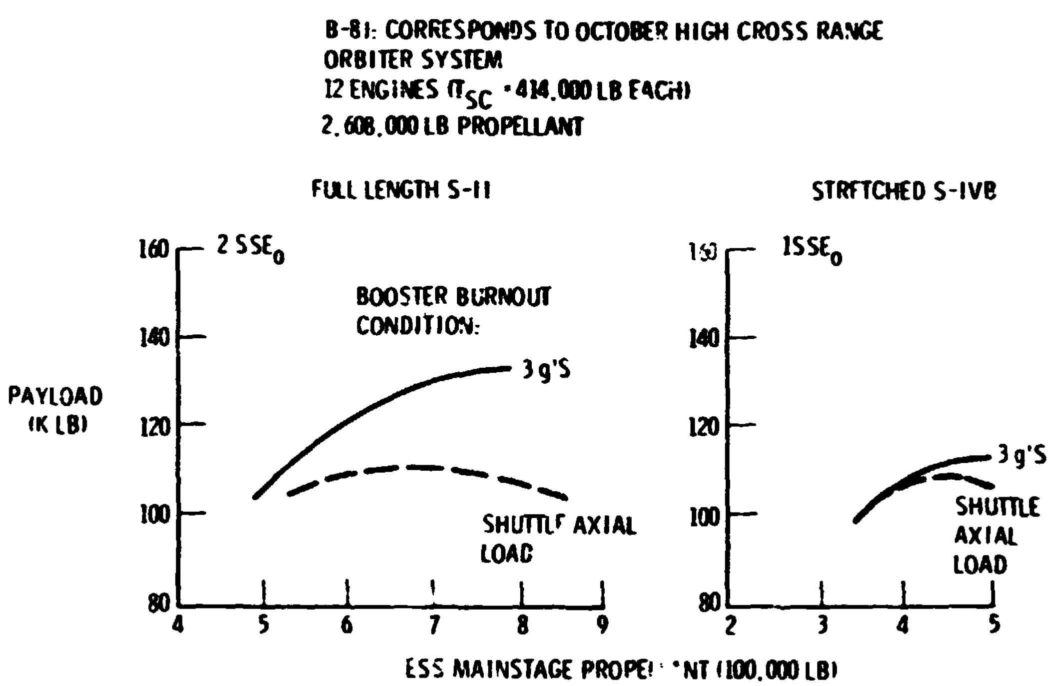


Figure 12. Effect of B-8J Booster on ESS Performance

(mounted aft on the booster) promised the lowest total cost per pound of payload to orbit. Later, at the conclusion of Phase A, even though a larger booster was employed, this basic result had not changed.

After the informal review on November 6, 1970, the then current 12-engine baseline booster for the high cross-range orbiter (gross weight: 3.15 million pounds) was selected for use with the ESS. As requested by the NASA project engineer on November 6, the ESS-payload matrix for further studies was reduced to the combinations in Figure 13. The weight statement for the performance analysis is given in Table 2. Performance ground rules are outlined in Table 3. Performance curves for determining the propellant loading are plotted in Figure 14. The final performance results are given in Figure 15. Several combinations of ESS-payload diameter are shown, with or without deorbit capability. Additional data are given in Figure 16 for the system recommended at the end of Phase A.

In the second part of the Phase A study, attention was directed toward the stability and control factors associated with the ascent trajectory of the combined system. The three aspects were studied: center-of-gravity (cg) tracking, pitch control, and roll-yaw control in a crosswind.

As propellant is burned by the reusable booster, the cg of the combined system moves vertically relative to the booster centerline and is farthest from the centerline at booster burnout. The cg also tends to move aft. Thus, tracking the cg is difficult in the latter part of the boost period. For a 4-degree cant angle of the booster engines, a 7-degree gimbal angle added to the 4 degrees encompasses all cases shown when the ESS is mounted forward on the booster. For the case of an aft-mounted ESS, cant or gimbal increase is needed to track the cg up to, and including, end boost. Assuming that the booster is designed with cant-angle adjustment capability, a cant increase of approximately 2 degrees (to 6 degrees) appeared to be desirable for ESS end-boost controllability. The cg tracking requirements for each of the ESS candidates are evident in Figure 17.

Pitch control during the aerodynamic portion of the ascent flight must be provided by gimbal deflection of the 12 rocket engines on the booster. Of particular interest is the high-q (dynamic pressure) region, where the flight Mach number is approximately 1.1. At this transonic Mach number, the center of pressure in pitch is generally well behind the cg of the combined system — a statically stable condition. In sideslip, the center of pressure (cp) may be ahead of the cg — a statically unstable condition. This condition was chosen for analysis of flight control because it is believed to represent as severe a control situation as any of the other configurations would be likely to present. The objective was to define a pitch command program that

	S II					S-IVB	NEW	
PHILOSOPHY	MIN-MOD	MIN MOD	MODIFIED	MODIFIED	MODIFIED	MODIFIED	ORBITER DERIVATIVE	ALTERNATE
MAIN ENGINES TYPE	J 2	SSE_0	J 2	SSE_0	J 2 SRM	J 2 SRM	SSE_0	SSE_0
NUMBER	5	2	5	2	2 (J 2) 6 (SRM)	1 (J 2) 6 (SRM)	2	2
PROPELLANT (K LB)	800	750	800	750	400 (J 2) 275 (SRM)	230 (J 2) 233 (SRM)	700	700
DIAMETER (FT)	33	33	33	33	33	21 67	33 (MAX)	27
OMS ENGINES TYPE	LEM-D	LEM-D	LEM-D	LEM-D	LEM D	SS ACPS	RL 10A	RL 10A
NUMBER	2	2	2	2	2	TBD	2	2
PAYLOAD								
FWD MOUNT (LB)	141,600	164,000	145 400	167,400	103 300	NA	NA	NA
AFT MOUNT (LB)	142,200	164 600	145,660	167,900	NA	106,600	193,000	195,500

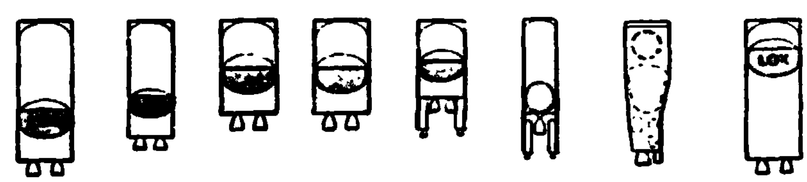


Figure 13. ESS-Payload Matrix (Reduced Number of Candidates)

Table 2. Weight Statement for Performance Trade Analysis

	FORWARD LOCATION					AFT LOCATION						
	MIN MOD SII		MOD SII (856 IN.)		MOD SII	MIN MOD SII		MOD SII (856 IN.)		NEW 27'D	ORB DER	S IVB
	5J-2	2 SSE_0	5J-2	2 SSE_0	2J-2 & SRM	5J-2	2 SSE_0	5J-2	2 SSE_0	2 SSE_0	2 SSE_0	1J2 & SRM
DRY STAGE	93270	87970	89970	84670	70570	93370	88070	90070	84770	77000	79695	40120
TRAP & RESID	10000	5660	9540	5560	8110	10000	5660	9540	5560	3700	3700	2100
RCS PROP.	1930	1930	1930	1930	1930	1930	1930	1930	1930	720	720	700
I.U.	8000	6000	8300	8000	8000	8000	8000	8000	8000	*	*	5000
END BOOST	113200	103560	109440	100160	88610	113300	103660	109540	100260	81500	84115	47920
M.S. PROP.	800000	750000	800000	750000	400000	800000	750000	800000	750000	700000	700000	230000
SRM PROP.					275540							234965
OMS PROP.	18500	19400	18500	19400	13800	18500	19400	18500	19400	13500	13500	8600
INTERSTAGE	13600	15000	13800	15000	14000	12700	14700	14200	14700	-	-	8770
SRM CASES					28440							18305
DRAG LINK	2500	2500	2500	2500	2500	6000	6000	6000	6000	6000	-	5030
AFT TRUSS	6500	6500	6500	6500	6500	-	-	-	-	-	-	500
GROSS ESS	953700	898960	940940	893660	828890	951180	894360	948840	888860	881800	797615	555800

*INTEGRAL SYSTEM – INCLUDED IN DRY STAGE

Table 3. Performance Ground Rules

- BOOSTER

  STAGING CONSTRAINTS: RESULTS IN RE-ENTRY COMPATIBLE WITH BOOSTER DESIGN

- MINIMUM LIFTOFF T/W = 1.20 G
  MAXIMUM BOOSTER T/W = 3.0 G
  MAXIMUM ESS T/W = 4.0 G

- ESS MAINSTAGE BURNOUT AT PERIGEE OF 400,000 FEET
  APOGEE OF 100 N MI
  55 DEGREE INCLINED ORBIT

- PAYLOAD DEFINED AS WEIGHT FORWARD OF PAYLOAD ADAPTER

  ADAPTER WEIGHTS REFLECTED ARE:

STAGE DIA	PAYLOAD DIA	ADAPTER WEIGHT
396 IN.	396 IN.	0
260	260	0
396	260	6300 LB
260	396	3800
324	260	2400
324	396	2200

- ESS FLIGHT PERFORMANCE RESERVE OF 300 FPS (1%)

- GUIDANCE UNITS ASSUMED

S-II	S-IVB	NEW STAGES
MODIFIED IU	MODIFIED IU	INTEGRATED AVIONICS
8000 LB	5000 LB	2900 LB

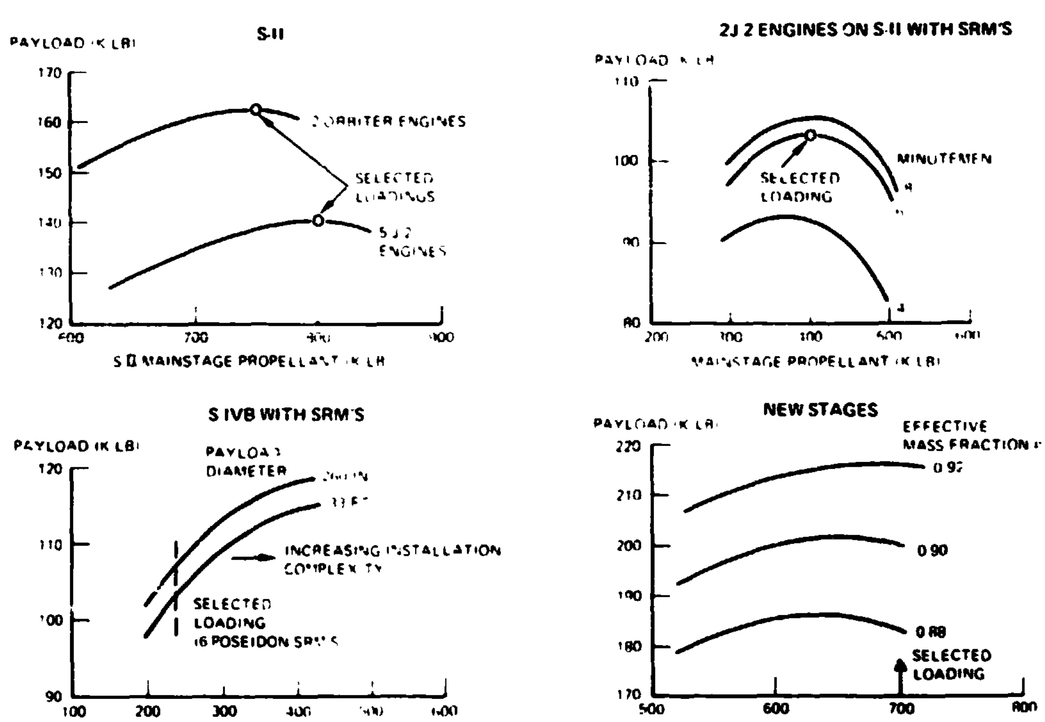


Figure 14. ESS Sizing, Propellant Loading

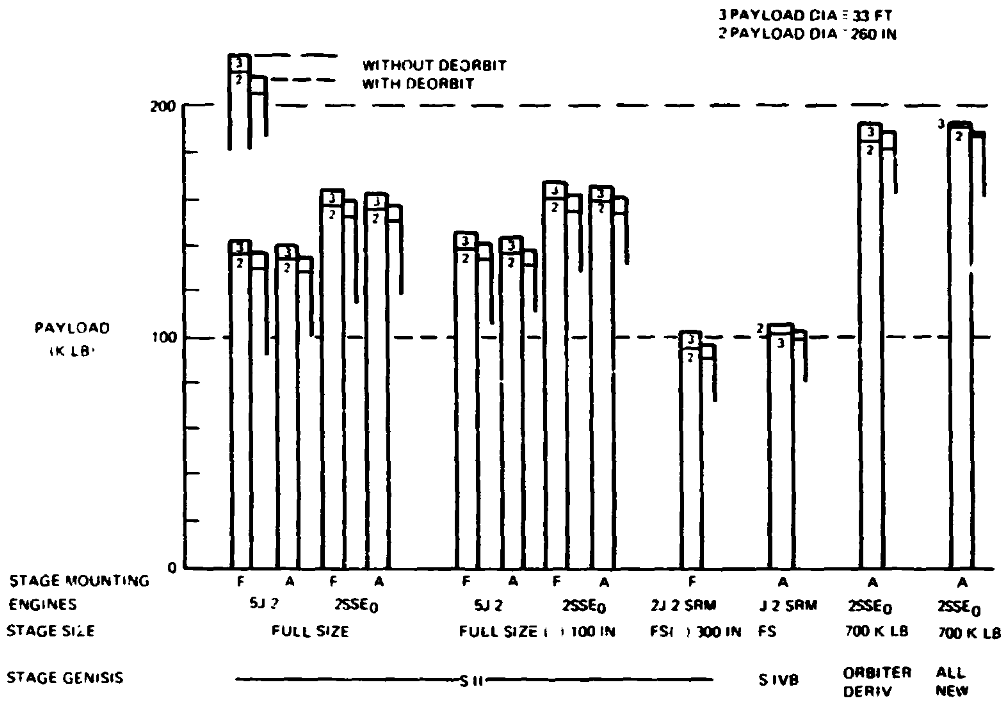
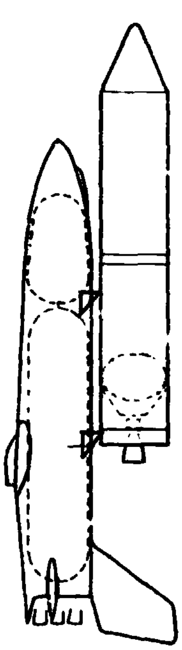


Figure 15. Performance Comparison of ESS Candidates—Design Reference Mission (No Contingency)



- DESCRIPTION: MS ENGINES 2 X SSE_0
  - MOUNTING AFT
  - LENGTH 71.3 FT
  - OMS 2 X LM-D
- GROSS PAYLOAD CAPABILITY 167,900 LB
  - USEFUL PAYLOAD AT 33 FT DIA 167,900 LB
  - USEFUL PAYLOAD AT 260 IN. DIA 161,600 LB
- S-II DERIVED ESS
  - MAINSTAGE PROPELLANT 750,000 LB
  - OMS PROPELLANT 19,400 LB
  - BURNOUT WEIGHT 92,300 LB
  - IU 8,000 LB
  - *BOOSTER ATTACH STRUCTURE 21,700 LB
  - GROSS WEIGHT 891,400 LB
- BOOSTER
  - MAINSTAGE PROPELLANT 2,543,200 LB
  - (OFFLOADED M.S. PROPELLANT) (64,300) LB
  - BURNOUT WEIGHT (WITH FLYBACK FUEL) 537,400 LB
  - GROSS WEIGHT 3,080,600 LB
- COMBINED SYSTEM
  - LIFTOFF WEIGHT 4,140,000 LB
  - LIFTOFF T/W 1.2
- BOOSTER ENGINE GIMBAL REQMT** ± 10 DEG

*5300 LB RECOVERABLE WITH BOOSTER

**OR EQUIVALENT GIMBAL + ADDED PRECANT

Figure 16. S-II-Derived ESS

would result in relatively small angles of attack and require gimbal deflections within the ±7 degrees available. This objective was found to be achievable.

Next, the effect of a 95-percent headwind was investigated. Gimbal angles less than ±7 degrees were sufficient for control during the aerodynamic portion of flight.

Lateral control involves both sideslip and roll effects. For an extreme case, the ESS/reusable booster combination without any load relief would have imposed on it a sideslip angle of 11.2 degrees at q_{max}. To trim this condition, both sideslip and roll effects require gimbal deflection components for both the ESS and the shuttle. The deflections greatly exceeded the ±7 degrees then available; hence, load relief is necessary for both the shuttle and the ESS, to minimize gimbal angle requirements. With a closed-loop load relief control system, both the ESS and the space shuttle appeared to be able to limit sideslip angles to ±2.5 degrees, and ±5 degrees appeared to be a reasonable design sideslip for loads. Figure 18 indicates (from a static analysis) that, to trim a β = 2.5 degrees, gimbal deflections under 5 degrees would be sufficient for both the shuttle and the ESS.

The limit attachment loads for the high cross-range orbiter are listed in Figure 19. For the propellant loadings selected, the candidate expendable second stages required at least one load greater than required for the orbiter, and hence involved some effect on the booster. These are shown in cross-hatch on the figure. Each of the loads quoted is the largest value derived from a load study of each configuration. A study was conducted to determine how payload shape, length, and weight would affect the attachment loads. The conclusion was that, by increasing the loads about 10 percent, all variations studied could be accommodated.

For an S-II-derived ESS, three attachment schemes were investigated. These are illustrated in Figure 20. By using a drag strut design, as illustrated in Figure 21, the ESS loads are less than S-II allowables except for relatively small local areas.

The capability, cost, and cost-effectiveness of the vehicles studied in the latter part of Phase A are listed in Table 4. The material presented shows that the largest payload could be accommodated by a "new-design" ESS, the lowest total program cost for the 10-vehicle program specified could be achieved by the S-IVB with solid rocket motors (at a considerable reduction in payload), the lowest total program cost per pound of payload to design reference orbit could be achieved by a shortened S-II with two orbiter engines, and the lowest recurring cost per pound of payload to design reference orbit also could be achieved by a shortened S-II with two orbiter engines.

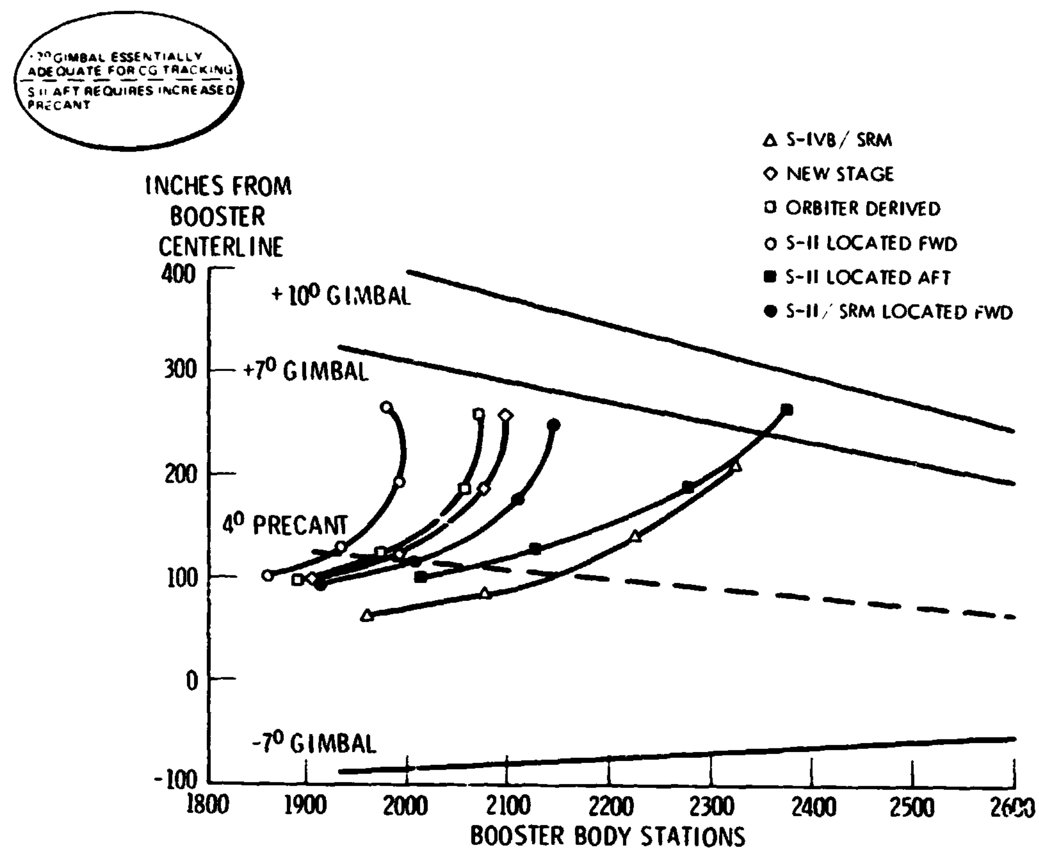
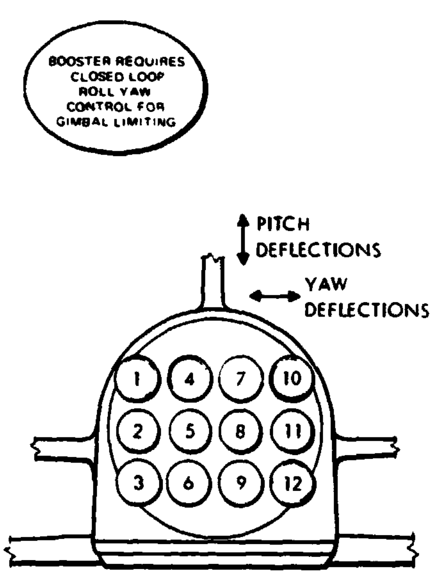


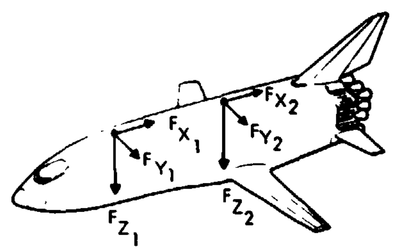
Figure 17. Mated Configuration CG Spectrum—ESS/MDAC Space Station



MAX q

GIMBAL DEFLECTION REQUIRED TO TRIM $\beta = 2.5°$				
DIRECTION	ENGINE NUMBERS	ESS FORWARD	ESS AFT	SHUTTLE
PITCH	1 THRU 6	4.0°	2.9°	-4.6°
	7 THRU 12	-1.6°	-2.9°	2.0°
YAW	1,4,7,10	3.1°	3.2°	-4.0°
	2,5,8,11	0.3°	0.3°	-0.7°
	3,6,9,12	-2.5°	-2.6°	2.6°
GIMBAL DEFLECTION COMPONENTS				
PITCH		1.2°	0.0°	-1.3°
YAW		0.3°	0.3°	-0.7°
ROLL		-2.8°	-2.9°	3.3°

Figure 18. Engine Gimbal Pattern (With Load Relief)



	FWD ATTACH.			AFT ATTACH.	
	F_{X_1}	F_{Z_1}	F_{Y_1}	F_{Z_2}	F_{Y_2}
ORBITER	2150	-200	±54	860	±138
S-II (AFT)	3365	-625	±166	1410	±62
S-II (FWD)	3374	-288	±174	789	±92
S-II (6 SRM)	3068	-240	TBD	713	TBD
S-IVB (6 SRM)	2150	-344	TBD	675	TBD
ORBITER DERIV	2904	-258	TBD	695	TBD
NEW STAGE	3267	-262	TBD	780	TBD

Figure 19. Booster/ESS Attachment Limit Loads (KIPS)

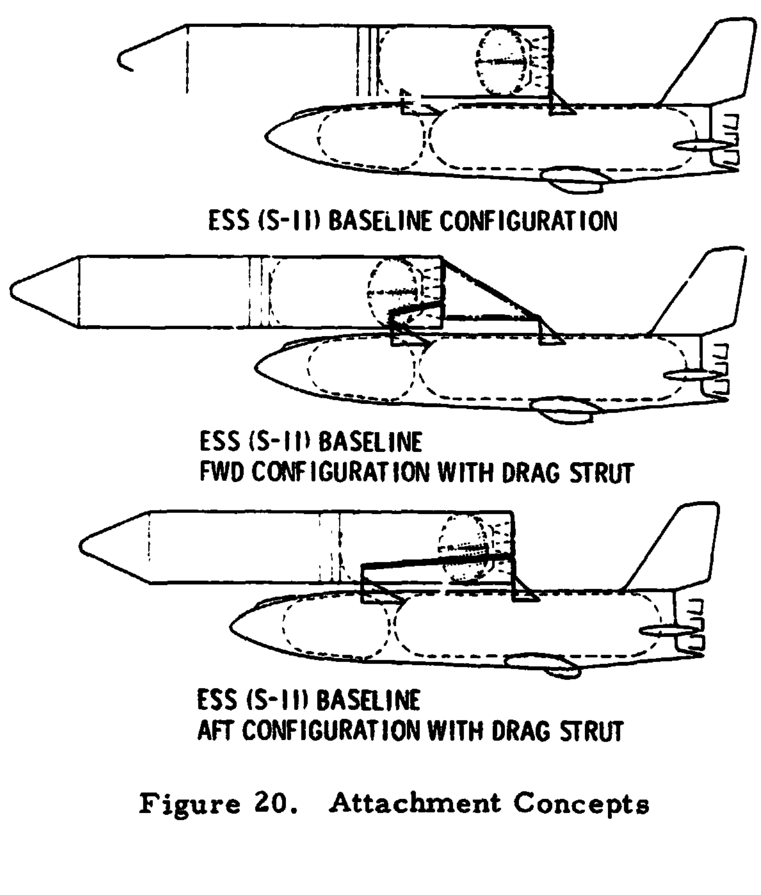


Figure 20. Attachment Concepts

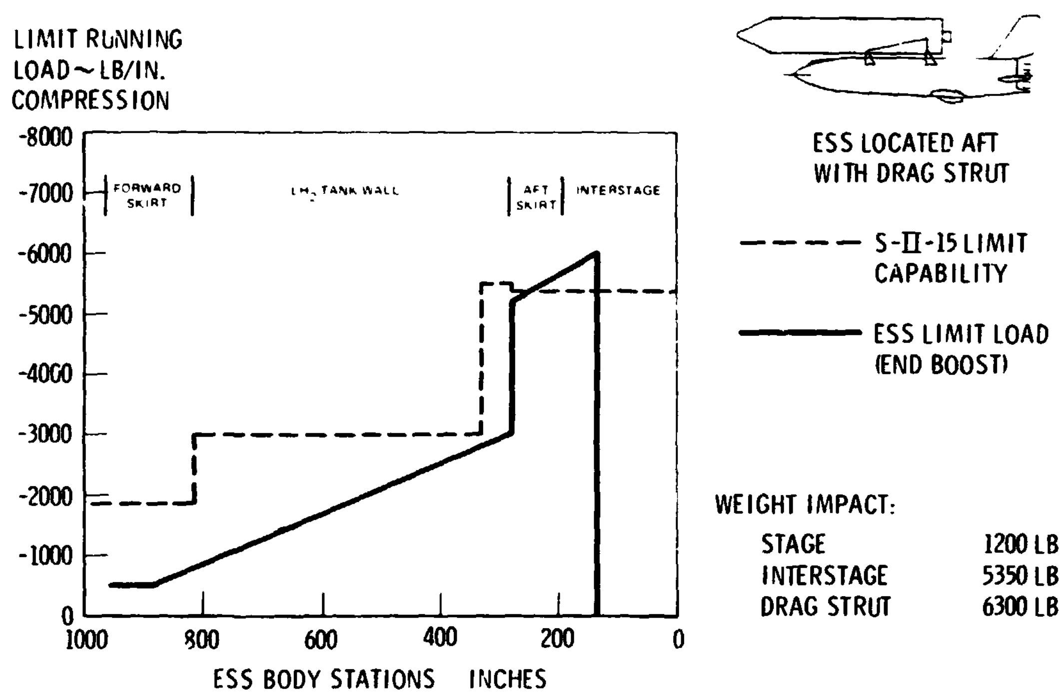


Figure 21. ESS Loads Summary—Aft Location With Drag Strut

Table 4. Capability, Cost, and Cost-Effectiveness

STAGE	SYSTEM	PAYLOAD, LB	TOTAL PROGRAM COST, $	TOTAL PROGRAM COST / LB PAYLOAD	RECURRING COST / LB PAYLOAD
S-II	283A5JF	142,000	638.74	450	348
	283A2SF	164,000	666.14	406	317
	283A5JA	140,500	633.47	451	343
	283A2SA	162,500	660.83	407	312
	263A2JF(S)	103,300	578.72	560	416
	273A5JF	146,000	634.84	435	335
	273A2SF	167,400	660.28	394	308
	273A5JA	144,000	627.63	436	331
	273A2SA	167,900	654.99	390	299
ORBITER DERIV	693F2SA	193,000	877.18	454	321
NEW DESIGN	692F2SA	195,500	1036.42	530	317
S-IVB	462A1JA(S)	106,600	452.92	425	316

BASED ON: CURRENT SHUTTLE BOOSTER,* 10 FLIGHTS, MAX PAYLOAD TO DESIGN REFERENCE MISSION

* INCLUDING SHUTTLE INCREMENTAL PROGRAM COSTS

The overall system evaluation was conducted in consideration, primarily, of the lowest total cost per pound of payload to design reference orbit by a vehicle which could accommodate a large percentage of the NASA-defined payloads. Further consideration was given to the technical requirements for developing the ESS system and the growth potential of the selected system. Table 5 summarizes this evaluation. The modified S-II, with two space shuttle orbiter engines, was selected in consideration of the above factors. This system was recommended to NASA for Phase B preliminary design studies.

The Phase A study conclusions were as follows:

1. The expendable second stage on a reusable space shuttle booster is technically feasible, and its impact on the shuttle system is small.
2. A modified S-II stage, powered by two space shuttle orbiter engines, is recommended for continued study in Phase B, based on:

   a. Cost-effectiveness
   b. Low risk
   c. Mission capability
   d. Growth potential

3. The booster mounting location for the ESS should be finalized subsequent to the January 1971 booster update.

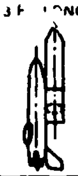
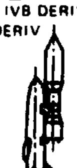
Introduced before the Phase B go-ahead was the concept of recovering high-value components from the ESS by the shuttle orbiter in orbit after completion of the ESS mission. The main engines and electronic packages were assumed to be recovered and reused. Revision in cost data, combined with the performance potential of the 3.94-million-pound booster (Table 1), resulted in greatly improved cost-effectiveness. With the assumptions made, the recurring cost per pound of payload to DRM was reduced to $175. This is illustrated in Figure 22.

On February 1, 1971, a technical directive was received from NASA that indicated, for the remaining portions of the Phase B study, emphasis should be placed on the short S-II stage with two space shuttle engines. Further, to facilitate an in-depth study up to mid-June 1971, baseline payloads should be consolidated into three. The specific payloads are indicated in Figure 2, along with the candidate payload spectrum for the Phase B study. Other ground rules to be used in Phase B were defined in an updated study control document dated February 1, 1971; they are included in Volume II, Book 1.

Table 5. System Evaluation

	EXPENDABLE SECOND STAGE CONCEPT				
	MOD S-II (FWD) 2 X SSE_0	MOD S-II (AFT) 2 X SSE_0	S-IVB 1XJ-2 (WITH SRM'S)	ORBITER DERIVATIVE 2 X SSE_0	NEW STAGE 2 X SSE_0
MAX PAYLOAD (270 NMI, 55° INCL) LB	167,400	167,900	106,600	193,000	195,500
COST					
NONRECURRING $ M	145	153	115	258	428
RECURRING $ M	515	502	338	619	608
TOTAL $ M	660	655	453	877	1036
$ / LB PAYLOAD: TOTAL / RECUR	394 / 308	390 / 299	425/316	454 / 321	530 / 317
TECHNICAL REQUIREMENTS					
BOOSTER MOD REQ	ATTACHMENTS & PRIMARY STRUCT.	ATTACH + PRIM STRUCT.	ATTACH + PRIM STRUCT.	ATTACH + PRIM STRUCT.	ATTACH + PRIM STRUCT.
BOOSTER WT, LB	12,000	19,000	3,000	7,200	9,500
STAGE MOD REQ	MIN MOD PRIMARY	MIN MOD PRIMARY	SRM'S + BEEFUP	–	–
STAGE WT, LB	-1200	-1100	+5,800	–	–
SHUTTLE ΔGLOW, LB	64,000	101,000	16,000	40,000	50,000
CONTROLLABILITY (+7°)	ACCEPTABLE	MARGINAL	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
GENERAL	ATTACH TRUSS REQ	DRAG STRUT REQ	ATTACH TRUSS REQ		
RISK	LOW	LOW	MEDIUM	MEDIUM	HIGH
MISSION CAPABILITY					
PAYLOADS DELIVERED (BY WT)	13 / 15	13 / 15	9 / 15	15 / 15	15 / 15
LAUNCH AZIMUTH	RESTRICTED	RESTRICTED	RESTRICTED	ALL AZIMUTH	ALL AZIMUTH
ONE ENGINE OUT	LIMITED	LIMITED	NONE	LIMITED	LIMITED
GROWTH POTENTIAL					
(LARGER SHUTTLE BOOSTER)	GOOD	GOOD	MARGINAL	GOOD	GOOD
(CHEM INTERORBITAL SHUTTLE MISSION)	EXCELLENT	EXCELLENT	POOR	EXCELLENT	EXCELLENT

ESS TECHNICALLY FEASIBLE
- ADEQUATE PERFORMANCE FOR LARGE LIFT MULTI MISSION CAPABILITY
- SYSTEM CONTROLLABLE SIMILAR TO SHUTTLE
- EFFECT ON SHUTTLE
COST-EFFECTIVE SYSTEM - SMALL GROWTH POTENTIAL WITH

	MAIN ESS PROPULSION	BOOSTER CHARACTERISTICS	GLOW K LB	ESS WT END BOOST K LB	PAYLOAD TO DRM K LB	RECURRENCE COST/LB TO DRM $/LB
S-II DERIVATIVE (71.3 F LONG) 	2 X SSE_0	LIFT OFF WT 3081 K LB	4140	100	168	299
	5 X J 2	MAIN PROPULSION	4140	110	144	331
	2 X J 2 + SRM	12 X 415 (SL) K LB	4069	89	103	416
	2 X SSE_0	GROSS WT 3940 K LB 12 540 (SL) K LB	5030	100	195	260 $\boxed{175}$
S IVB DERIV DERIV 	1 X J 2 + SRM	LIFT OFF WEIGHT 3142K LB MAIN PROPULSION 12 X 415 (SL) K LB	3801	48	106	316
NEW ORBITER 	ORB DIR 2 X SSE_0	LIFT OFF WEIGHT 3142 K LB	4132	84	193	321
	NEW 2 X SSE_0	MAIN PROPU PROPULSION 12 X 415 (SL) K LB	4139	82	196	317

- S-II ESS WITH UPDATED BOOSTER
- HIGH COST COMPONENTS RECOVERED FROM ORBIT BY SHUTTLE
- ALL NASA PAYLOADS BY WT

COST BASED ON 10 FLIGHT PROGRAM AT 2 LAUNCHES YEAR
DRM - DESIGN REFERENCE MISSION (270 N MI 55°)
SSE_0 - SPACE SHUTTLE ENGINE - ORBITER

Figure 22. Summary of ESS Phase A Study

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PHASE B VEHICLE DEFINITION

ESS/REUSABLE BOOSTER

The space shuttle vehicle system consists of a reusable booster and a reusable orbiter. For launching very large payloads, the ESS/reusable booster system, composed of the same reusable booster combined with an expendable second stage, can be utilized, as illustrated in Figure 23. The selected expendable second stage for the Phase B study is a direct derivative of the Saturn S-II, which was developed for the Apollo program, and utilizes many existing components. Most of the remaining components are shuttle-developed equipment. The basic ESS primary structure is largely from the S-II, with one 99-inch LH_2 tank ring omitted. The ESS uses two space shuttle orbiter engines, which are interchangeable with those used on the orbiter. A new thrust structure is needed for these engines.

Two 10,000-pound-thrust orbit maneuvering system (OMS) engines, proposed for development for the orbiter, are identified for ESS use; fourteen 2100-pound-thrust attitude control propulsion system (ACPS) thrusters, proposed for development for both the orbiter and reusable booster, will serve similarly for the ESS. Also, most of the components required in the ESS avionics subsystem will be derived from orbiter avionics. The reusable booster requires only minor structural changes to accommodate the ESS. Such changes logically would be incorporated during the normal design process to best permit the system to operate efficiently. The payloads that the ESS system can accommodate may vary considerably in weight and size, with essentially no change to the ESS system from one payload to another. Figure 24 shows the selected ESS system and specified payloads; Figure 25 illustrates the basic configuration for the selected combined system.

The concept for the overall operations of the ESS system is outlined in the previous section. The design reference mission profile is shown in Figure 26. One aspect of the ESS supplementary space shuttle capability is that flights will be scheduled relatively infrequently. When the flights are made, however, large, important payloads will be involved. The relatively infrequent flight rate of the ESS system will permit these flights to be made with a shuttle fleet of the size presently planned, with minimal impact on the existing NASA shuttle traffic model.

As the shuttle payloads are defined and the traffic model becomes more firm, in addition to handling ESS payloads, the economic efficiency of utilizing the ESS system for some of the payloads in the traffic model will deserve

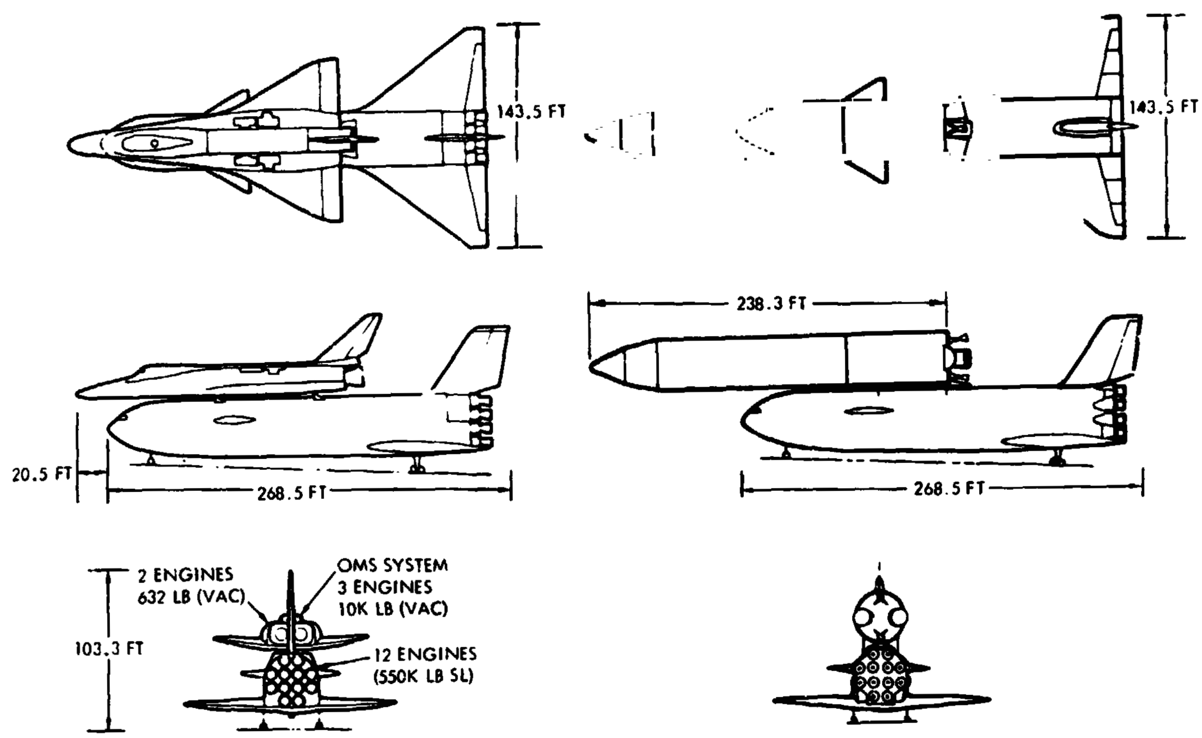


Figure 23. Phase B Shuttle/ESS System Comparison

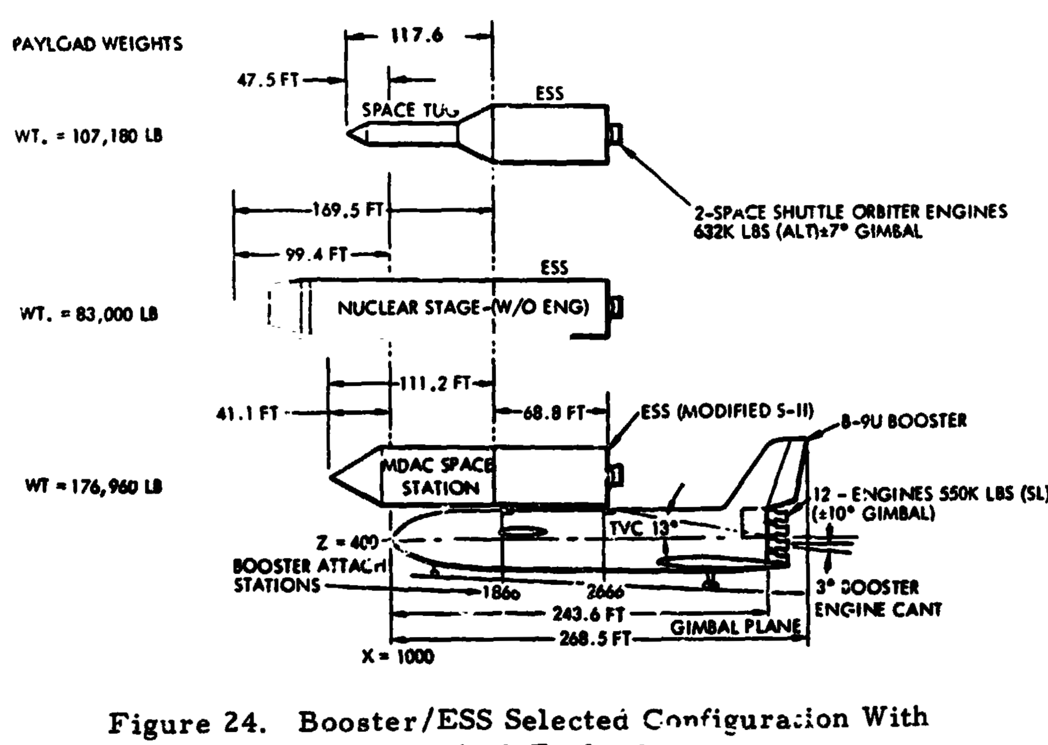
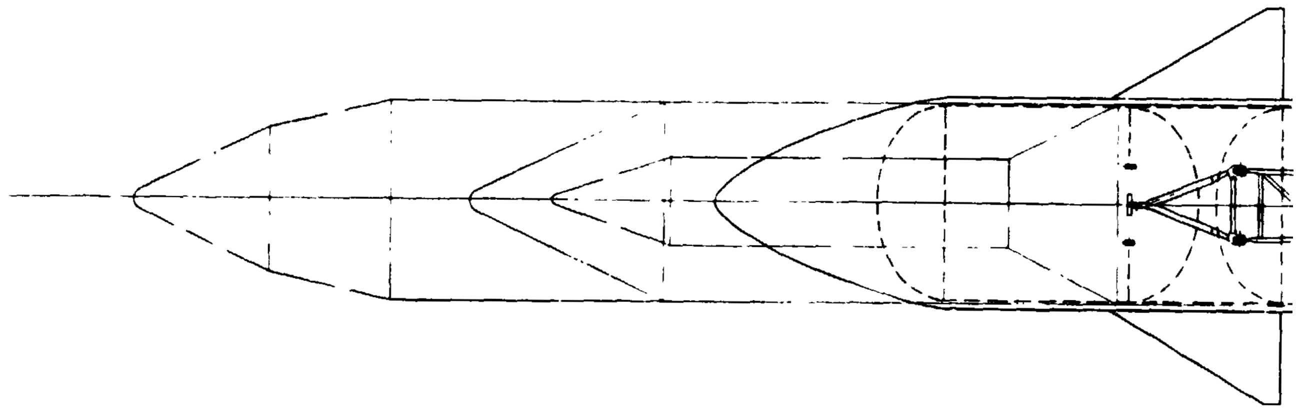
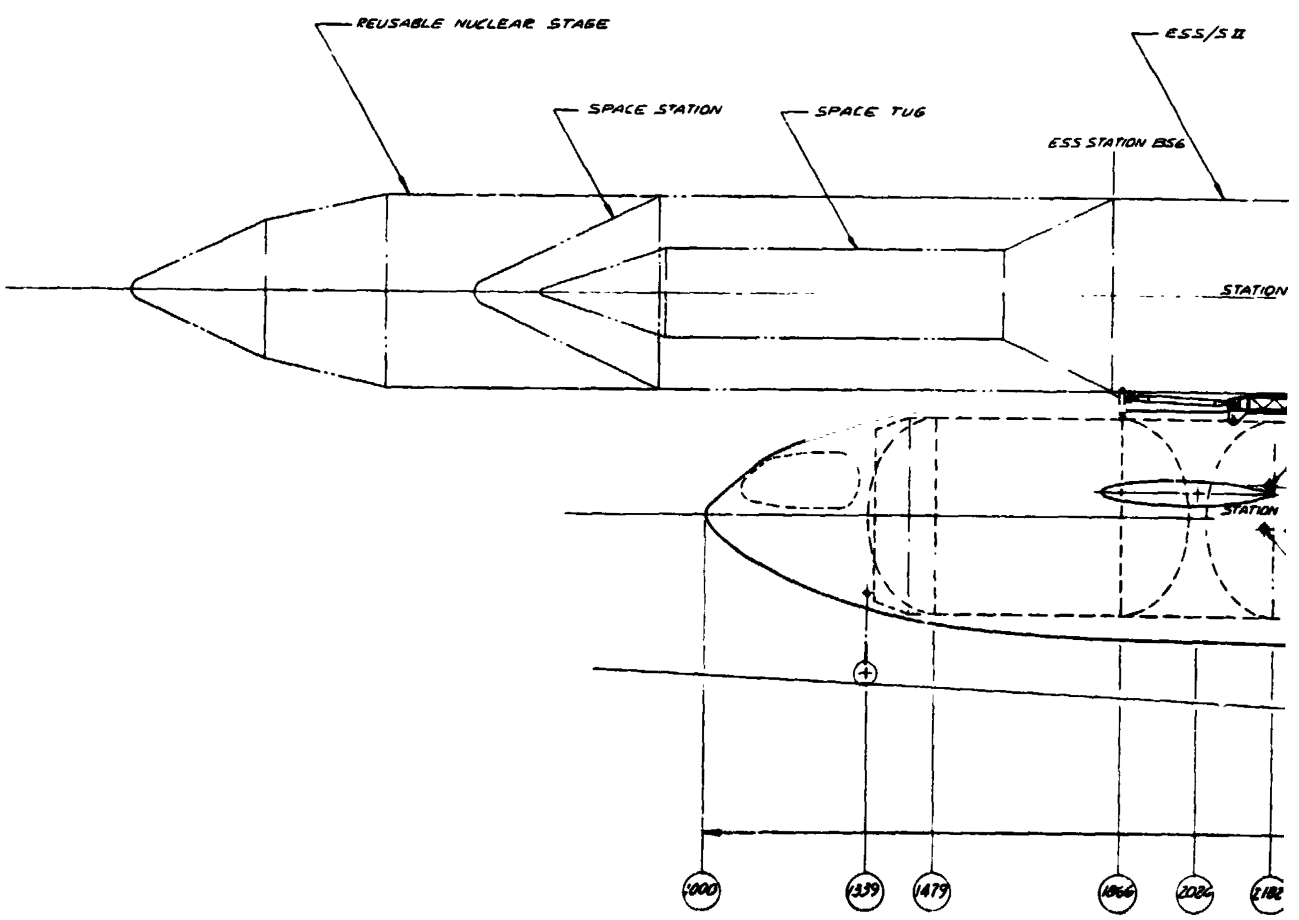


Figure 24. Booster/ESS Selected Configuration With Specified Payloads

FOLDOUT FRAME 1





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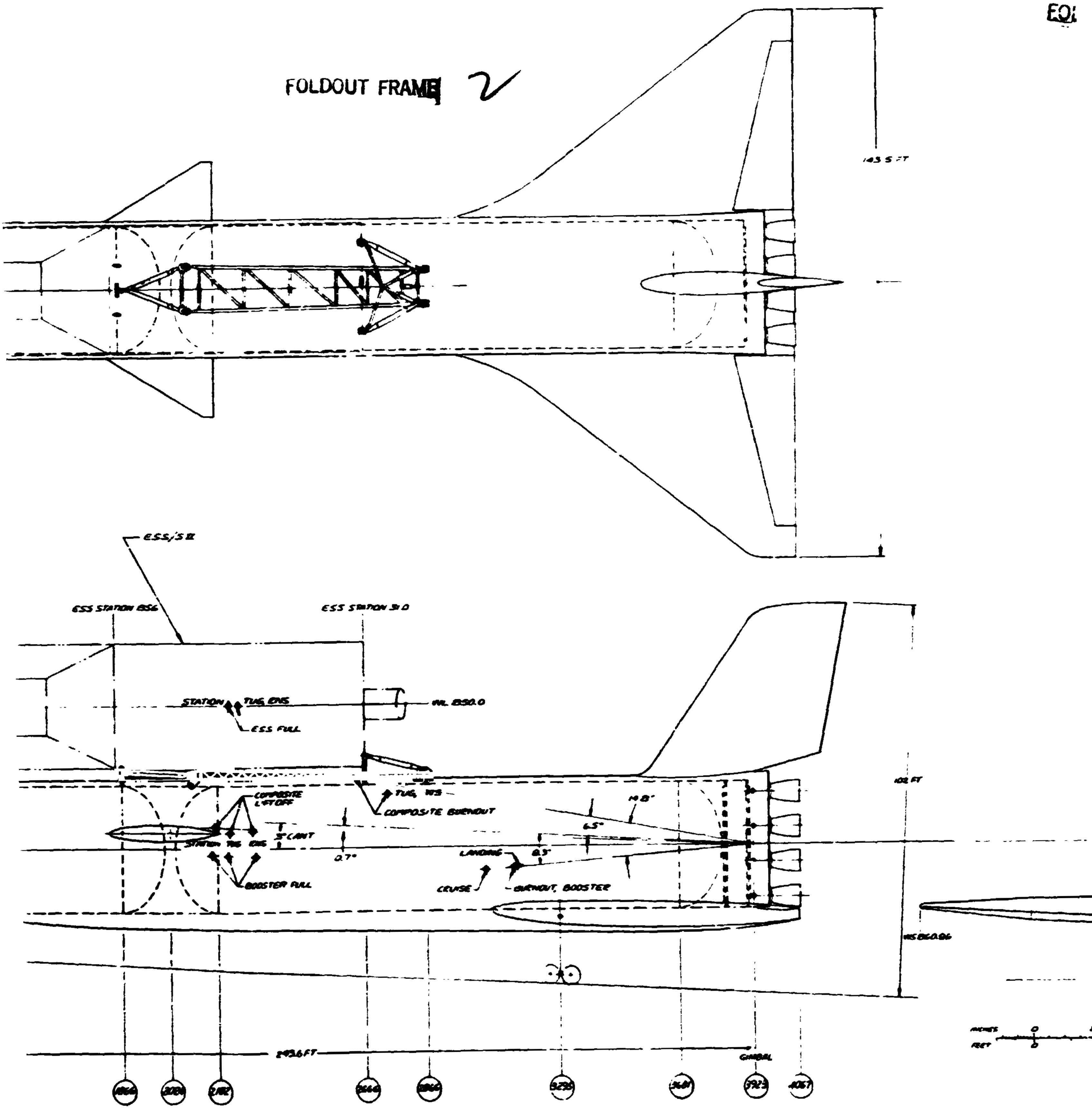

Figure 25. Basic ESS/B-9

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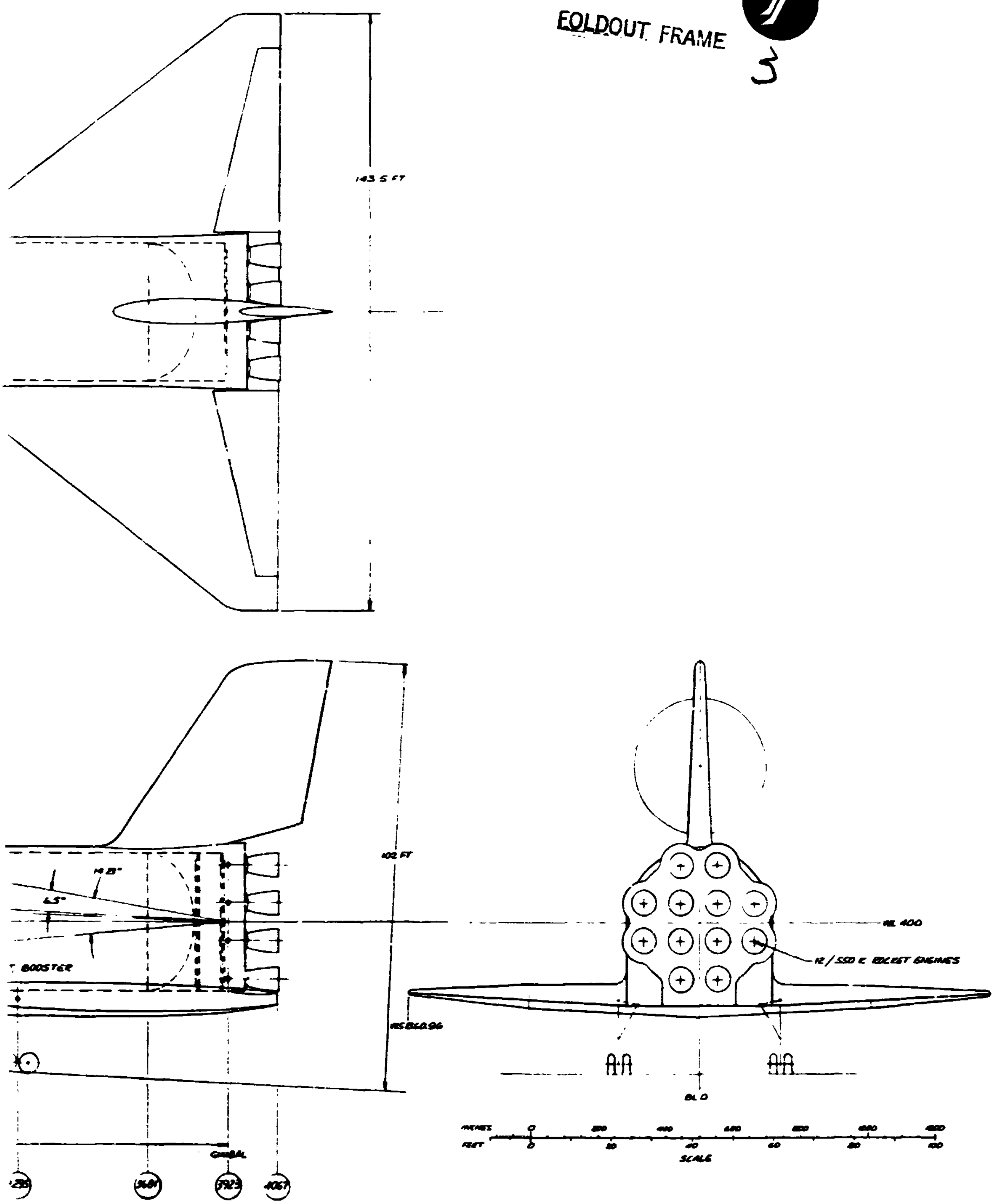


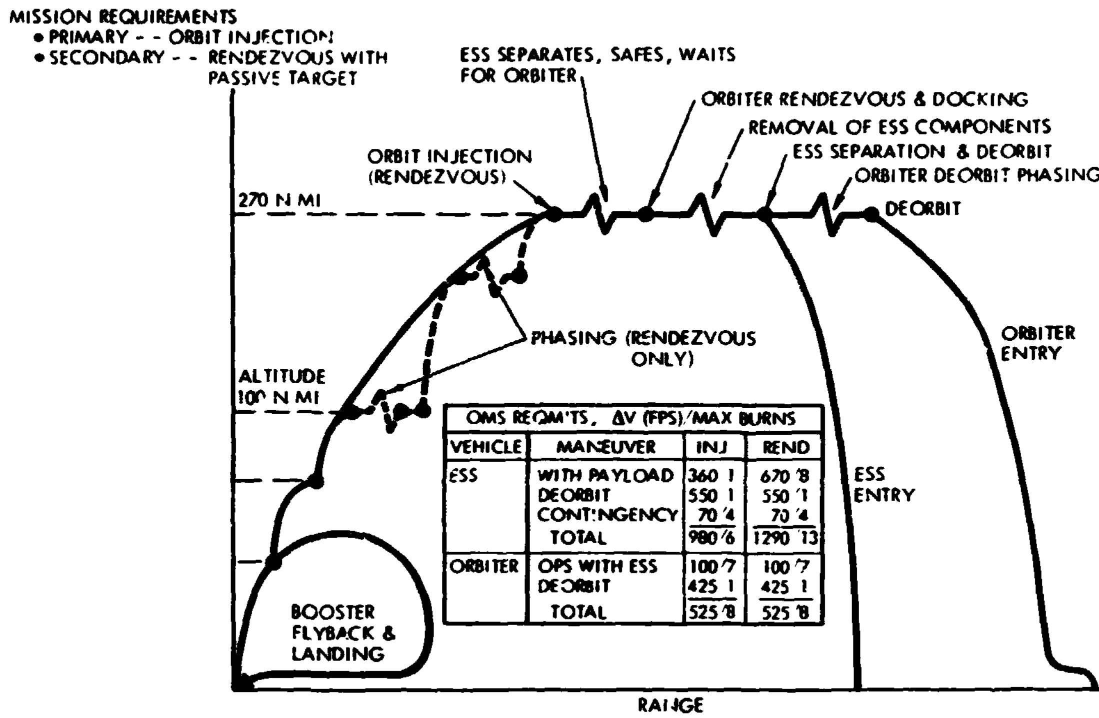
Figure 25. Basic ESS/B-9U Booster Configuration

considerat If sufficient ESS efficiency for even a few payloads is demonstrated, additional payloads of interest can be planned for the shuttle, perhaps without additional funding. Some payloads, by nature, can be clustered and flown simultaneously to their operating point in space. Typically, for those payloads which require high-energy trajectories, and which will operate as well or better when launched concurrently (compared with the same payloads launched sequentially), the ESS offers potential. For example, a group of geosynchronous equatorial satellites may be desirable for communication. For this purpose, they all may be finally located in the same basic orbit (altitude, velocity, and inclination) and need only be separated from each other in longitude. A satellite system of this nature could be a candidate for cluster launching by an expendable second stage system and a single third propulsive stage. A feature of this approach is that in sequentially launching each payload to geosynchronous equatorial orbit, an independent and costly guidance, navigation, and control system is required. Also, the third propulsive stage required to place these payloads into the prescribed orbit itself is an expensive boost stage.

Early high-energy flights probably will involve propulsive third stages which are expendable. In the case of the ESS system, the ESS accelerates the payload cluster and the third propulsive stage to a high-energy ellipse. One GN&C system will be sufficient with just one third propulsive stage, with restart capability, to place each satellite payload from the cluster at its prescribed longitudinal location in the geosynchronous equatorial orbit. If five to ten such payloads could be clustered, the overall ESS system may offer direct economic benefits for such specialized missions. Efficiency would accrue from the reduction in number of expendable propulsive third stages along with reduced supporting costs. The goal associated with the ESS system when utilized to augment the space shuttle system is to assist in magnifying the aggregate final payload of the total shuttle system for the available funding investment. With further investigation of this approach, the greatest benefits from the payloads themselves should evolve, and such could be expected to have the effect of accelerating additional usage of the shuttle system.

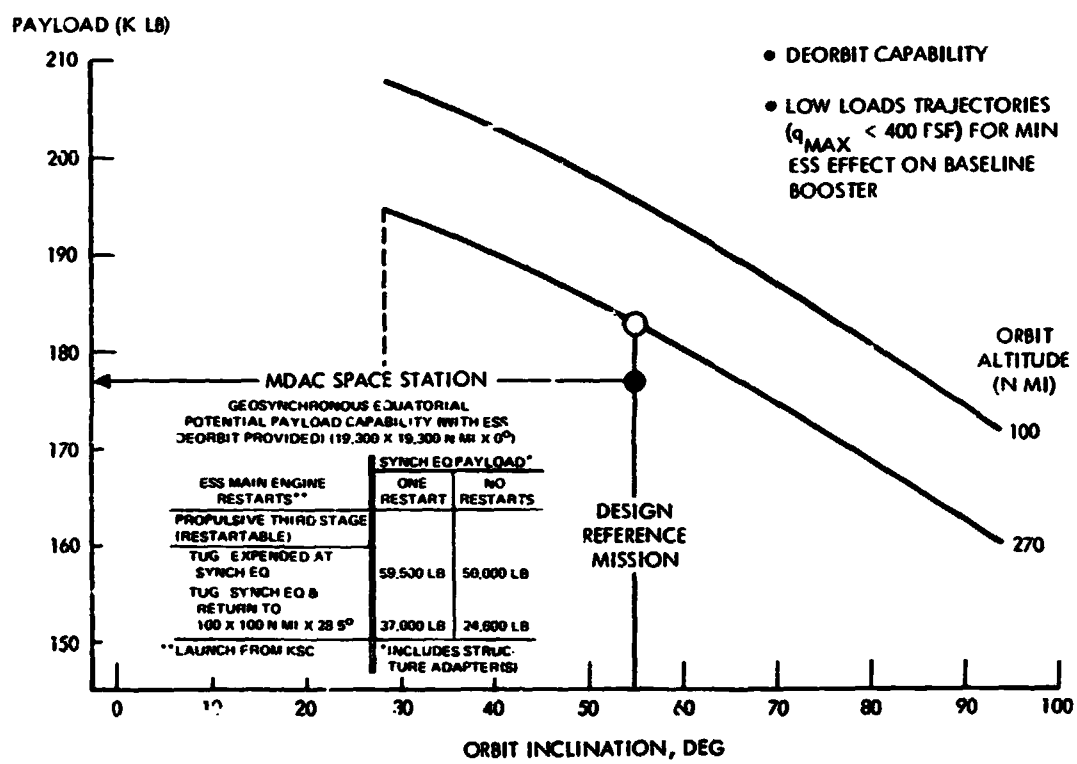
The payload capability of the selected ESS system is illustrated in Figure 27. The inset shows the geosynchronous equatorial potential payload capability of the ESS (with tug). This capability is substantial. These figures are consistent with the design approach discussed in the following paragraphs.

At the outset of the ESS study, the shuttle system was limited to a 3.5-million-pound gross lift-off weight and a main propulsion system thrust not exceeding 415,000 pounds per engine. The reusable booster portion of this vehicle system therefore was limited to a gross weight of about 2.7 million pounds. With this booster size, the initial study indicated that an ESS derived from the Saturn S-II would be relatively payload-limited.



OMS REQM'TS, ΔV (FPS)/MAX BURNS			
VEHICLE	MANEUVER	INJ	REND
ESS	WITH PAYLOAD	360/1	670/8
	DEORBIT	550/1	550/1
	CONTINGENCY	70/4	70/4
	TOTAL	980/6	1290/13
ORBITER	OPS WITH ESS	100/7	100/7
	DEORBIT	425/1	425/1
	TOTAL	525/8	525/8

Figure 26. Design Reference Mission Profile



GEOSYNCHRONOUS EQUATORIAL POTENTIAL PAYLOAD CAPABILITY (WITH ESS DEORBIT PROVIDED) (19,300 X 19,300 N MI X 0°)

ESS MAIN ENGINE RESTARTS**	SYNCH EQ PAYLOAD* ONE RESTART	SYNCH EQ PAYLOAD* NO RESTARTS
PROPULSIVE THIRD STAGE (RESTARTABLE)		
TUG EXPENDED AT SYNCH EQ	59,500 LB	50,000 LB
TUG SYNCH EQ & RETURN TO 100 X 100 N MI X 28.5°	37,000 LB	24,800 LB

**LAUNCH FROM KSC

*INCLUDES STRUCTURE ADAPTER(S)

Figure 27. Performance Capability of Baseline ESS System

However, during the course of the Space Shuttle Phase B Definition Study, the size and thrust of the reusable booster increased. Because of this trend, the utilization of an S-II-derived ESS increased in attractiveness, since more nearly the full orbital payload potential of the S-II-derived ESS became possible without significant effect on the reusable booster. That is, the dual purpose of the reusable booster became possible with extremely small effect on its primary function as the space shuttle booster.

Whereas, with full propellant tanks, a net orbital payload capability potential of between 250,000 and 300,000 pounds exists with the selected ESS, the baseline system has been defined to meet NASA-specified payload requirements. The upper payload weight is 176,960 pounds. This requires an ESS system lift-off gross weight of 992,000 pounds, which must be boosted from the ground on the baseline reusable booster. This ESS system weight is somewhat greater than the lift-off weight of the baseline orbiter vehicle; hence, the reusable booster engines are throttled to a greater extent to reduce peak acceleration for the ESS mission from that for the shuttle mission. Peak acceleration reduction will minimize loading on the booster by the ESS. Two of the specified payloads are much lighter in weight than the heaviest payload. If propellant loading is kept constant in both the reusable booster and the ESS, the light payloads would arrive on orbit with a large amount of propellant remaining in the ESS. Too much ESS residual propellant is not an advantage, because the remaining propellant must be dumped to safe the vehicle after reaching orbit. If propellant is dumped through the main engines, first LO_2, then LH_2, the time required must be considered since the ESS lifetime is limited to 24 hours, by which time it must be deorbited. Also, since recovery of ESS components by the orbiter is planned, the propulsive effect of dumping large amounts of propellant needs to be offset by careful and somewhat complicated maneuvers.

The selected approach for propellant loading is to offload both the booster and ESS in sufficient amounts to leave a comfortable, but not excessive, margin. If only the ESS were offloaded, the booster would accelerate to a velocity too high for normal staging; this also would increase the flyback range required. Propellant dumping in normal flight is not planned for the booster. Hence, the selected approach is for both vehicles to be offloaded when a light payload is flown. For each of the specified light payloads, lift-off gross weight has been reduced significantly below 992,000 pounds. Lower weights lead to lower loads, but also require more booster engine throttling. The maximum throttling specified for the space shuttle engine is 50 percent of its normal power level.

At the beginning of Phase B of the ESS study in February 1971, the baseline shuttle reusable booster was very nearly sized to its final configuration. Twelve 550,000-pound-thrust engines were selected for the booster. Sufficient payload performance with the ESS system to meet all specified requirements was easily achievable, with margin to spare. To keep structural modifications to the booster to a minimum, and to avoid imposing any requirement for a flight test stage because of high loadings, the design approach was adopted to emphasize low loading on the booster by the ESS.

To achieve low loadings between the specified payloads and the booster, variables such as ESS/booster relative fore-and-aft location, the addition of aerodynamic fins where appropriate, changes to the nose cone shape for the several payloads, and related aerodynamic factors were given consideration. However, the need to produce a large reduction in loads was felt to be a key issue. Hence, alteration of the fundamental flight trajectories was believed to be an approach that would yield benefits for each payload. To obtain low aerodynamic forces, trajectory shaping was employed. This gave low maximum dynamic pressure (q) values, at the sacrifice of some of the aforementioned payload margin. The result was as expected—lower aerodynamic loads were calculated than had been the case at the beginning of Phase P, along with reduced aerodynamic loads through greater engine throttling on the booster.

Along with the low-load trajectory approach is the requirement for the reusable booster to control the mated system throughout the aerodynamic phase of flight. Gimbal angles of ± 10 degrees are provided by the main engines. Loads due to the design wind profile, including gusts, must be considered. Such winds are superimposed on the no-wind, low-load trajectories to determine actual aerodynamic loads. Sufficient control may be available, therefore, but if not used properly can produce excessive air loads during mated ascent flight. The Space Shuttle Phase B Study determined that load-reducing control methods are needed for the high-dynamic-pressure-region of flight. This high-q region is not specifically defined, but, in general, covers the time frame from perhaps 60 to 100 seconds after lift-off. To accomplish load reduction for this interval, gimbal limiting of the booster's 12 rocket engines is necessary in the pitch plane, and closed-loop load relief with the control system is needed in the yaw plane. In roll, use of the booster vehicle's wing-mounted elevons is necessary for a short period near maximum dynamic pressure to assist the booster's rockets in controlling the vehicle without excessive rocket gimbal angles. These flight control factors are similar to those for the shuttle and will vary only in the adjustment (software) requirements for the ESS flights.

To permit analysis of the aerodynamic loads and the controllability during aerodynamic flight, detailed aerodynamic estimates were made at the beginning of Phase B. These estimates were used in automatic computations of the loads on the vehicles and the control of the combined system. Wind tunnel models of each payload/ESS configuration were built. An existing reusable booster model was combined with each payload case. Preliminary wind-tunnel tests performed at Marshall Space Flight Center provided data for representative key flight conditions. Reduction of the wind tunnel data led to basic confirmation of the previous stability estimates insofar as effects on control are concerned.

Other factors considered for the ascent phase of ESS system flight include thermal analysis and acoustic environment. The shuttle thermal effects on most areas of the booster during ascent are more stringent than during ESS ascent. The thermal effects on the ESS during ascent are somewhat greater than are imposed on the S-II during an Apollo flight—hence, an erosion barrier has been added to the external insulation on the ESS to account for the higher heating values caused by proximity to the booster. Local thermal protection around attachment fittings also is needed.

Acoustic environment of the booster imposed on the ESS is similar to that imposed on the orbiter. The basic ESS design differs from the orbiter, however, and the effects of such environment remain to be evaluated in detail.

Each of the trajectories for the specified payloads meet the requirements for staging defined for the booster. The separation sequence is a very important, but short, time in the ascent flight. Upon near depletion of propellant in the booster, the separation sequence is: booster thrust is reduced; ESS engines are started; the vertical hold-down restraints on the ESS/booster attachment mechanism are disconnected. The booster accelerates faster than the ESS, for a brief time, and the pivoting attachment links rise at their forward ends and lift the ESS/payload combination. Links to the ESS are then severed, and full ESS thrust is reached. As separation occurs, the engines on the booster are shut down. From initiation to completion, the separation sequence lasts somewhat less than five seconds.

To attach the ESS to the reusable booster, a special attachment mechanism is required. This basically stems from the fact that the booster is designed to carry the axial (fore and aft) loads from the orbiter at the forward attachment fitting. Only vertical and side loads are carried at the aft fitting. The ESS derived from the S-II basically is designed to carry compressive loads; therefore, a means for transferring the axial load from the aft end of the ESS to the forward booster fitting is desirable. A fixed-platform concept has been selected; this requires that the orbiter attachment links on the booster be removed during flight preparation, and the platform with additional links be installed for ESS flight. The basic operation of the separation system is identical to the shuttle case, as described above. After the ESS flight, the booster flies back to its base, and the fixed platform is removed and the orbiter linkage is reinstalled during the maintenance cycle.

After separation from the booster, the ESS accelerates to a low orbit. The ESS separation dynamics are controlled by the two main engines. These engines each develop a maximum vacuum thrust, with nozzles extended, of 632,000 pounds. The ESS main engines burn only to the initial orbit, after which the auxiliary propulsion system is used.

Once it has delivered its payload into orbit, the ESS stage can become hazardous space debris. Controlled deorbit into an uninhabited ocean area is, therefore, a mission requirement. The feasibility of deorbiting to a safe area is primarily dependent on footprint size. The footprint is an area calculated to include debris which reaches the surface of the earth. The footprint is influenced by reentry velocity, vehicle attitude at initiation of reentry burn (firing angle), and attitude and debris scatter due to vehicle breakup upon reentering the earth's atmosphere. Analysis conducted during the Phase B study has established values for these key parameters. The resulting maximum footprint length is 1520 nautical miles; a value of 60 nautical miles was estimated as a reasonable width. As shown in Figure 28, this footprint easily fits into most large ocean areas. The ESS generally has one or two deorbit opportunities per orbit.

ESS VEHICLE

Physical Characteristics

The ESS primary structure consists of the S-II LO_2 tank, LH_2 tank with one 99-inch cylinder removed, a new thrust structure, and a new aft skirt and modified forward skirt, which incorporate the fittings for attaching the ESS to the space shuttle reusable booster. These are shown in Figure 29. The ESS general arrangement is shown in Figure 30.

The main propulsion system consists of two space shuttle orbiter retractable nozzle engines mounted to the new thrust structure. Deflectors are attached to the aft skirt to preclude direct airstream impingement on the retracted engines during first-stage boost. The main propulsion system (MPS) is used to propel the ESS from booster staging to initial orbit only. Subsequent orbital transfers and deorbiting are accomplished with two smaller orbital maneuvering system (OMS) engines mounted to the thrust structure. Attitude control is provided (when neither the MPS nor OMS engines are operating) by 14 thrusters located in the two LH_2 feed-line fairings. The 10,000-pound-thrust OMS engines and the 2100-pound-thrust thrusters are those being developed for the space shuttle orbiter and are fed by common tankage mounted on the thrust structure.

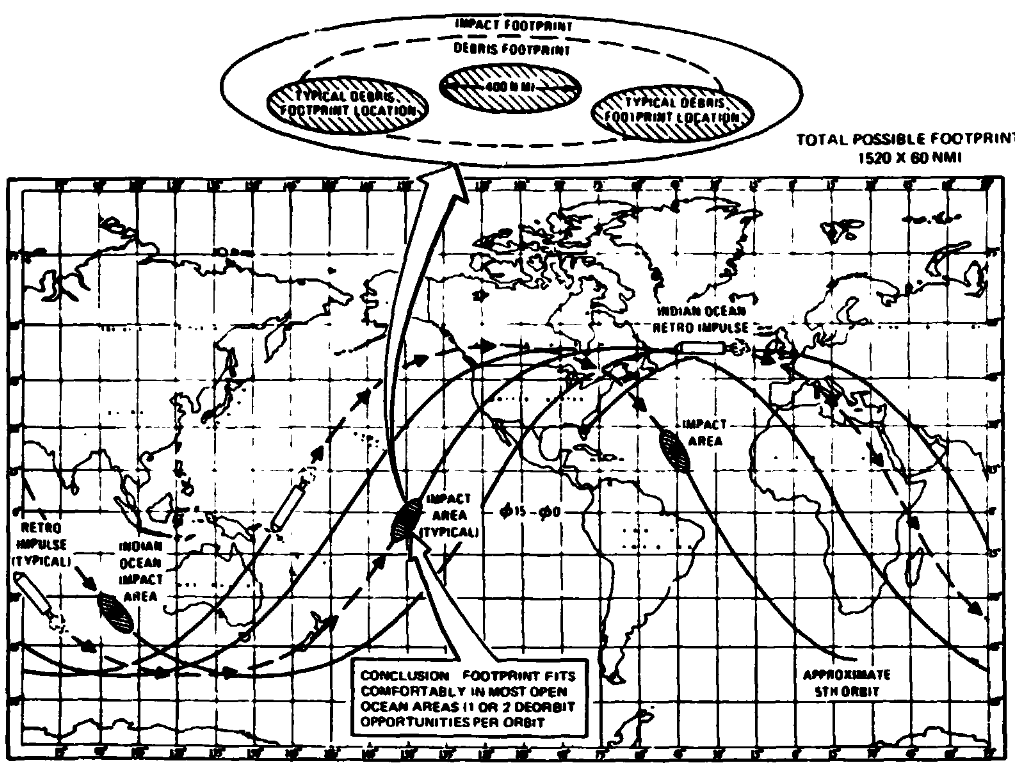


Figure 28. ESS Impact Areas

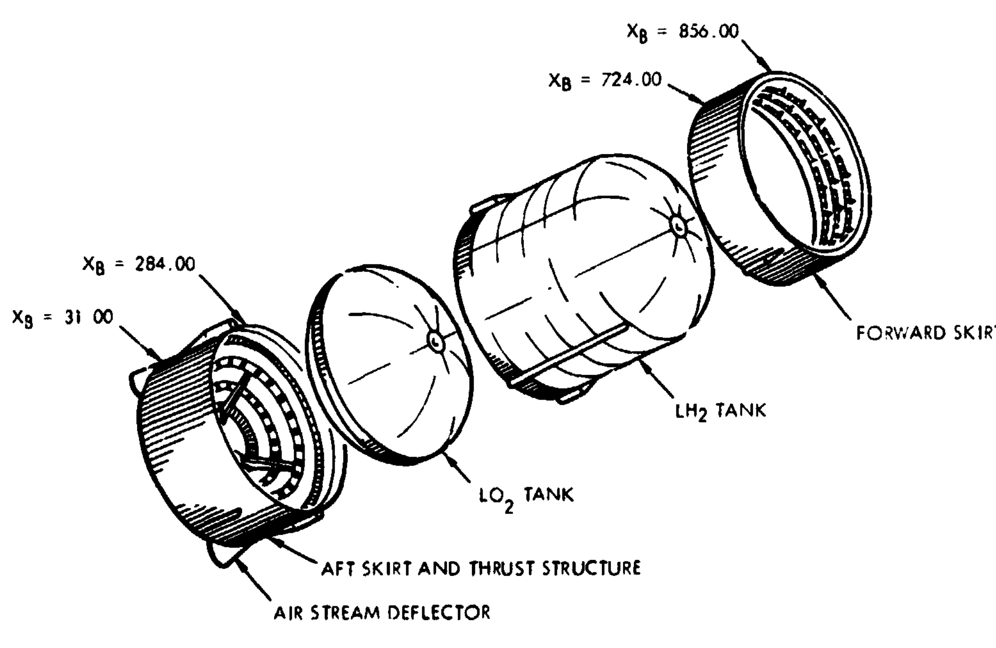


Figure 29. ESS Structural Arrangement

A docking port is integrated into the LH_2 feed-line fairing to provide space shuttle orbiter docking for retrieval of the main propulsion engines and guidance equipment prior to ESS deorbit.

Subsystems

Structures

The ESS structure makes maximum use of current S-II structural components and consists of five major subassemblies: a forward skirt, an LH_2 tank, an LO_2 tank, an aft skirt, and a thrust structure. Modification to the S-II structural components for conversion to the ESS are shown in Figure 31.

The forward skirt is a cylindrical semimonocoque aluminum shell with ablative insulation on local areas of high-protuberance heating. It provides for attachment of the ESS payloads and the forward attachment to the space shuttle reusable booster. Payload separation is accomplished by an ordnance device similar to that developed for the Saturn S-IVB/Apollo. Deformation of this device, upon detonation of a self-contained explosive charge, severs payload-to-ESS attaching tension straps. Subsequent physical separation occurs with firing of two forward-facing jet thrusters.

The LH_2 tank is an aluminum cylinder closed at the forward end by an S-II foam-insulated bulkhead and at the aft end by a bulkhead common with the LO_2 tank. The common bulkhead, which is identical to that on the S-II, is an adhesive-bonded sandwich assembly employing aluminum alloy face sheets and a fiberglass phenolic honeycomb core. The core is evacuated during flight to provide a thermal barrier between the LH_2 and LO_2 tanks. The cylindrical portion is a semimonocoque structure employing the S-II spray-on foam insulation as a thermal protective system capped with a new polyimide composite shingle-type erosion barrier to protect the foam insulation from aerodynamic erosion during atmospheric boost. Attachment of this shingle-type erosion barrier provides for substitution and attachment of a high-performance insulation and shingle-type meteoroid barrier for expansion of the ESS basic mission to the chemical interorbital shuttle mission.

The aluminum aft bulkhead is not insulated and is identical to that on the S-II, except that the sump is redesigned to provide for two orbiter engine feed-lines rather than the current five J-2 engine feed-lines on the S-II. The aft skirt is a cylindrical semimonocoque aluminum shell with ablative-type insulation on local areas of high-protuberance heating and a closeout base heat shield at the aft end. The skirt provides for the aft attachment to the space shuttle booster and protects the main propulsion engines and thrust structure from aerodynamic loads and heating during first-stage boost.

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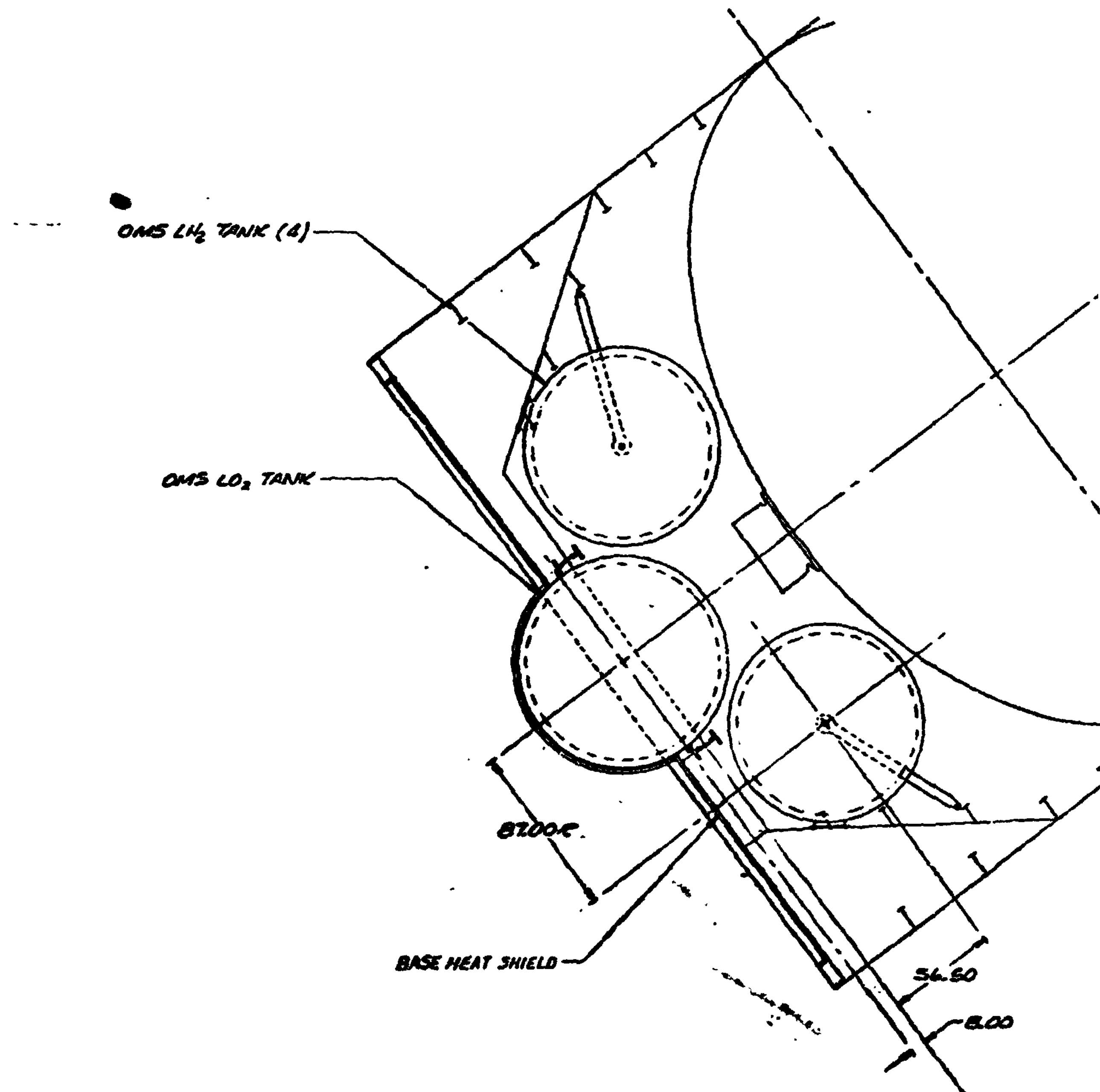

SECTION A-A [10]

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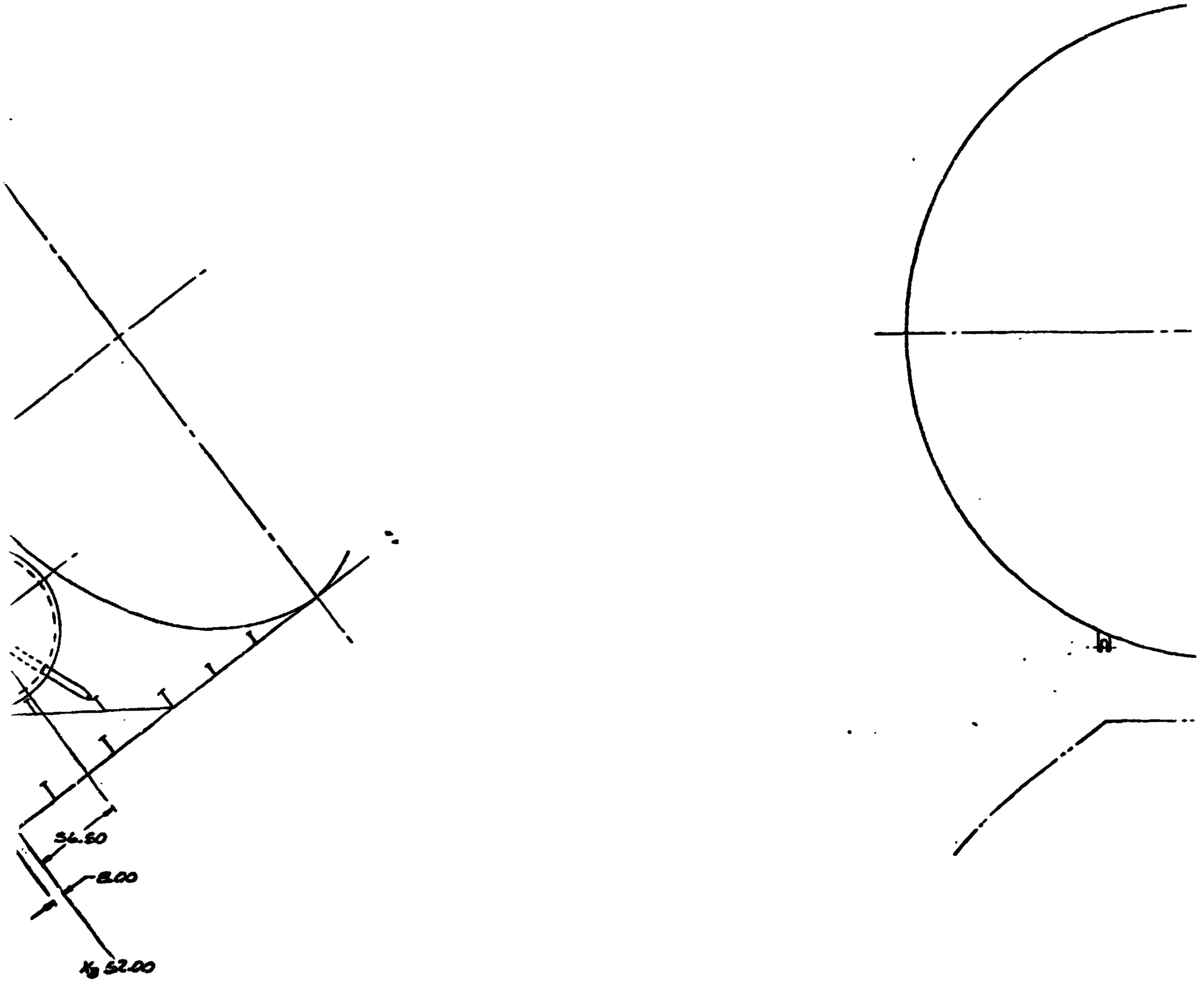

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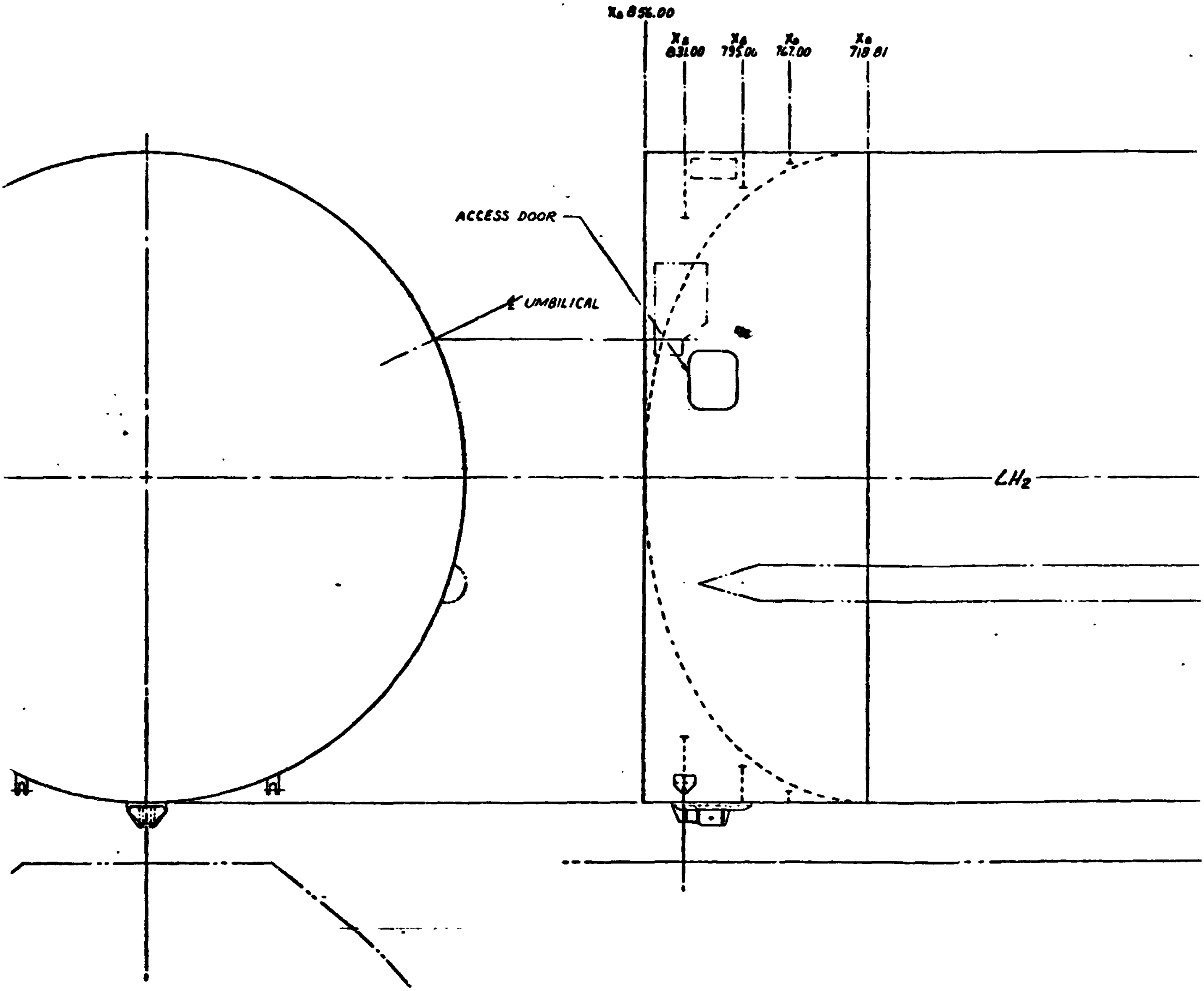

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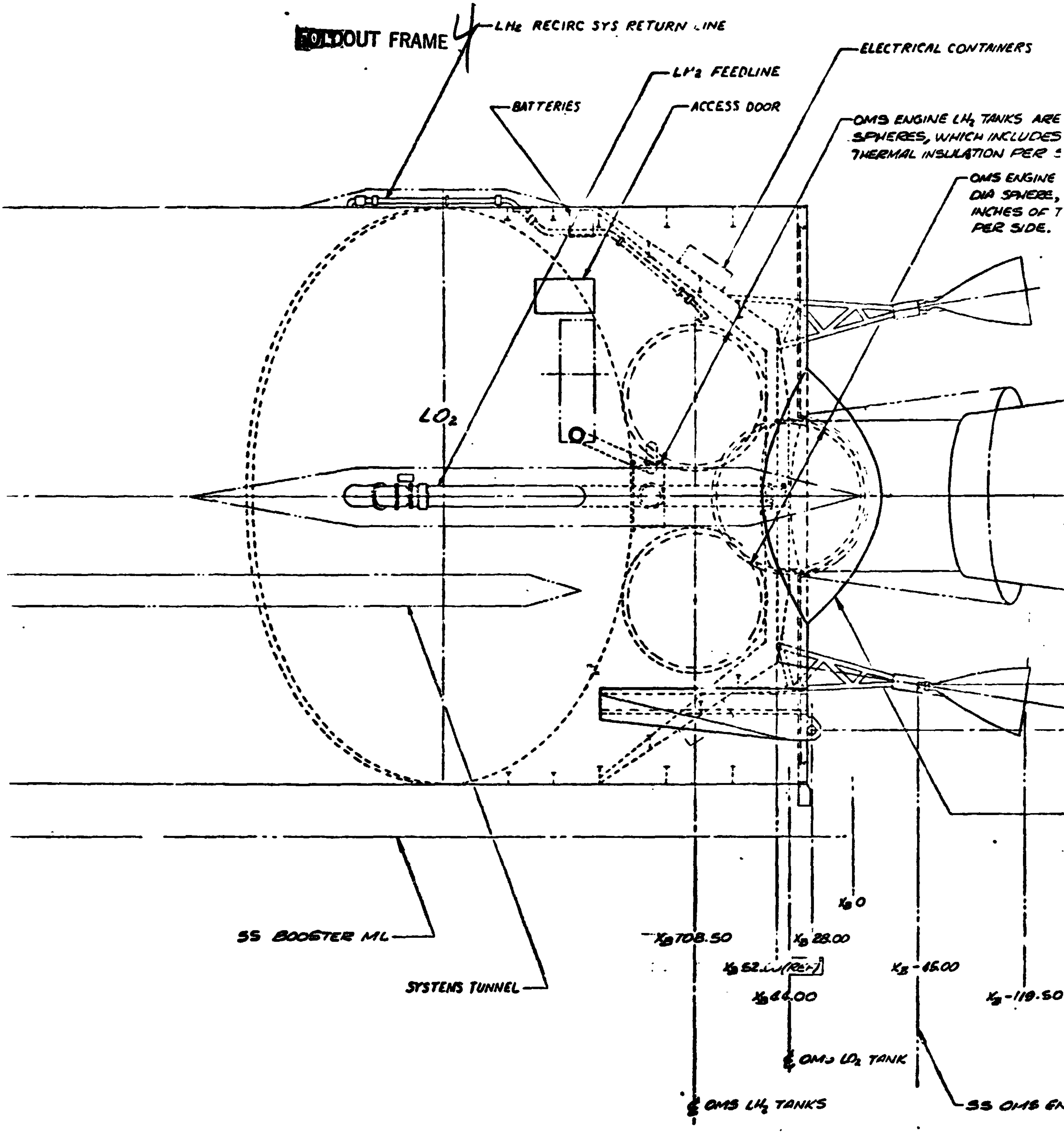
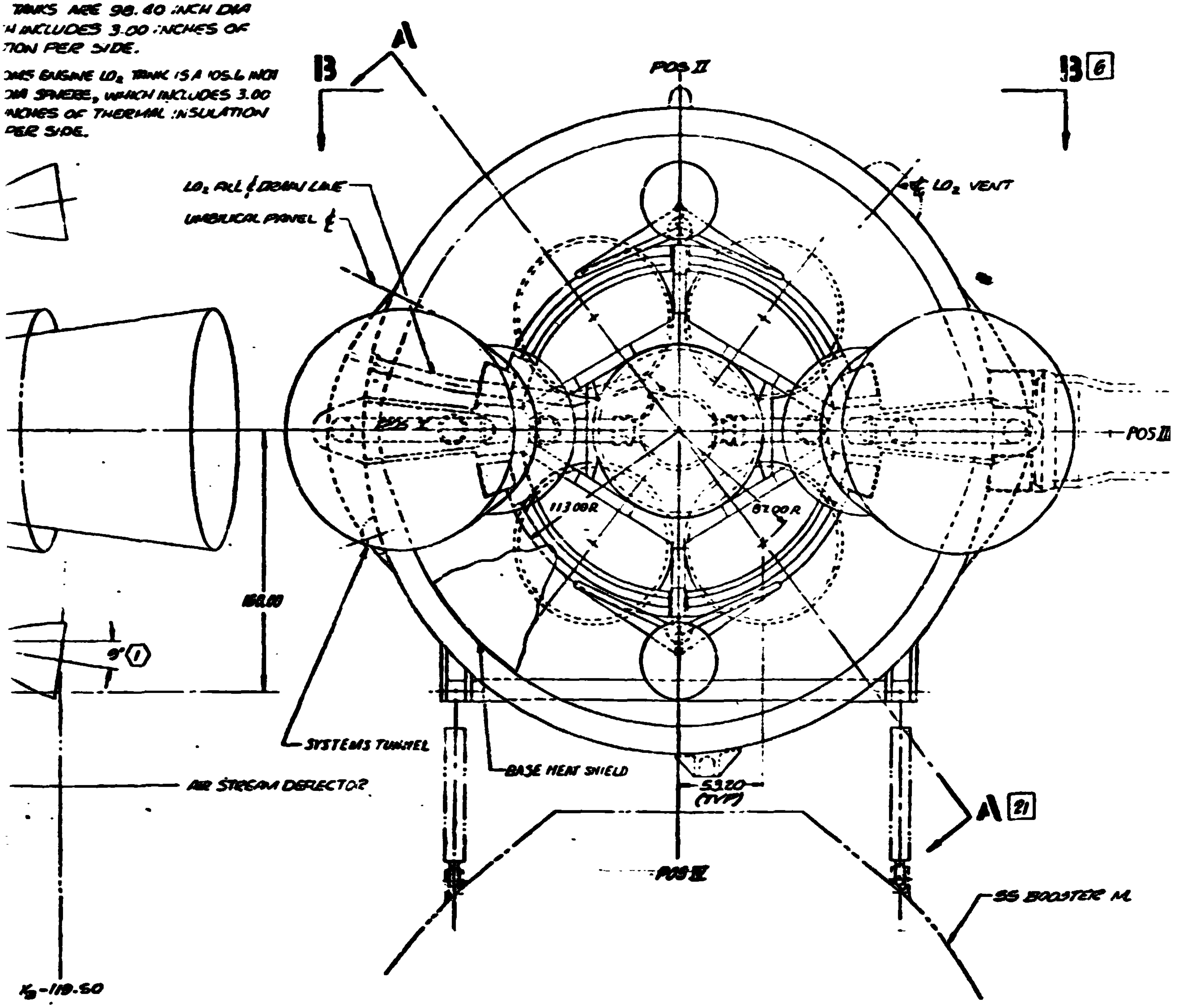


FOLDOUT FRAME 5

ITAINERS

TANKS ARE 98.40 INCH DIA
H INCLUDES 3.00 INCHES OF
TION PER SIDE.

OMS ENGINE LO_2 TANK IS A 105.6 INCH
DIA SPHERE, WHICH INCLUDES 3.00
INCHES OF THERMAL INSULATION
PER SIDE.



S OMS ENGINE GIMBAL PLANE

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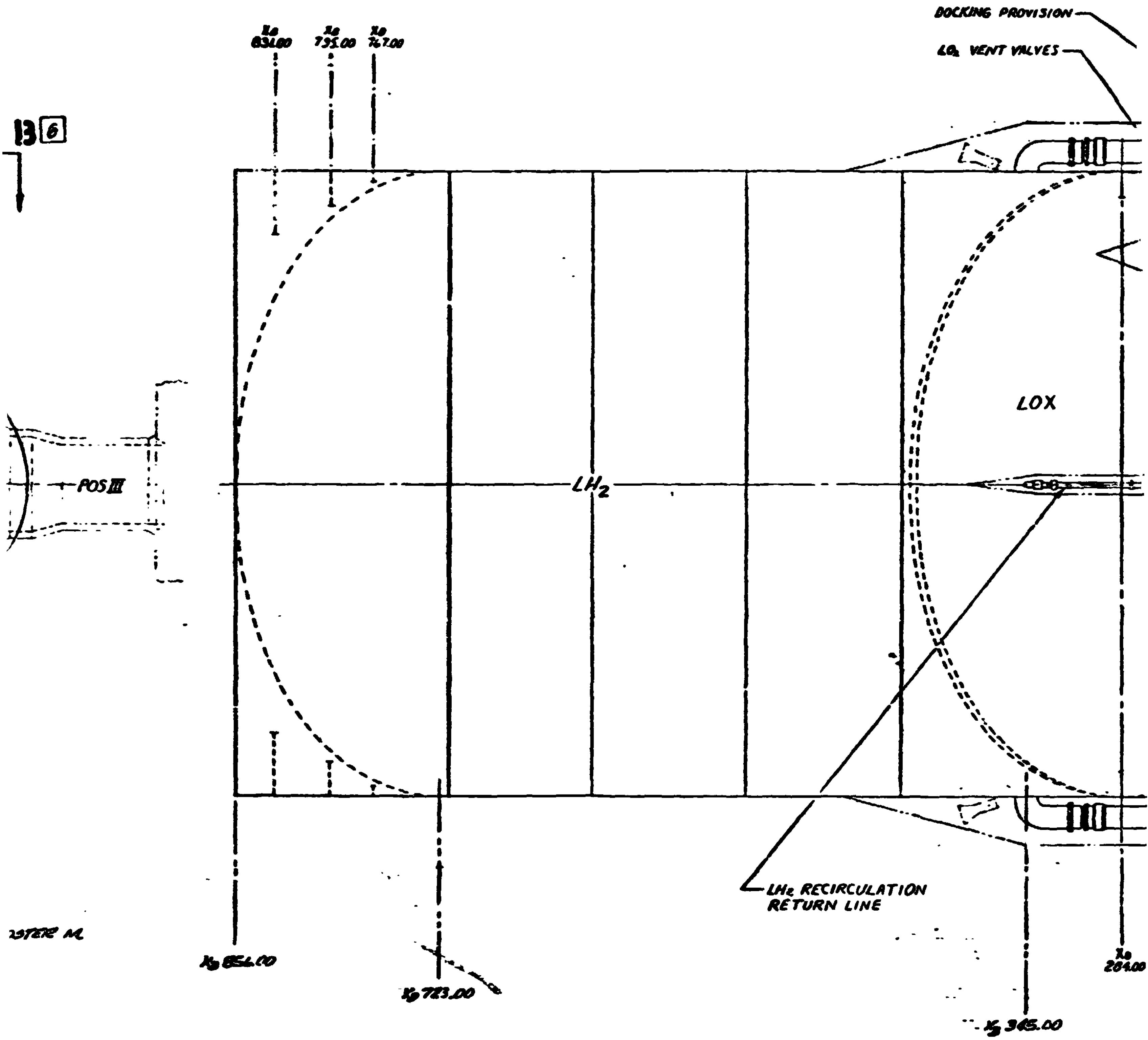


VIEW 13-13 10
ROTATED 90° CCW

FOLDOUT FRAME 1

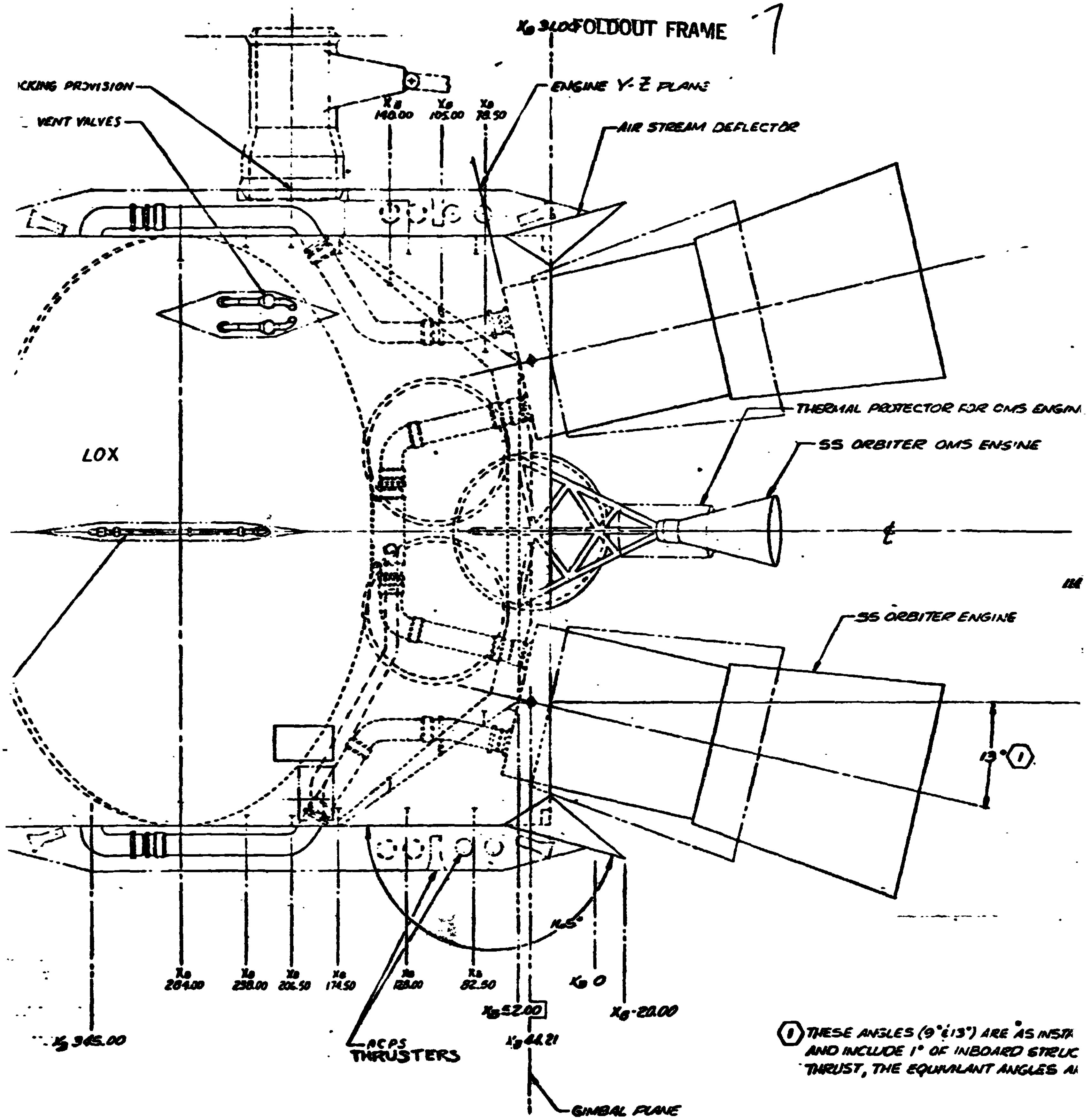


Figure 30. ESS General Arrangement (Draw

FOLDOUT FRAME 7

FOLDOUT FRAME 8

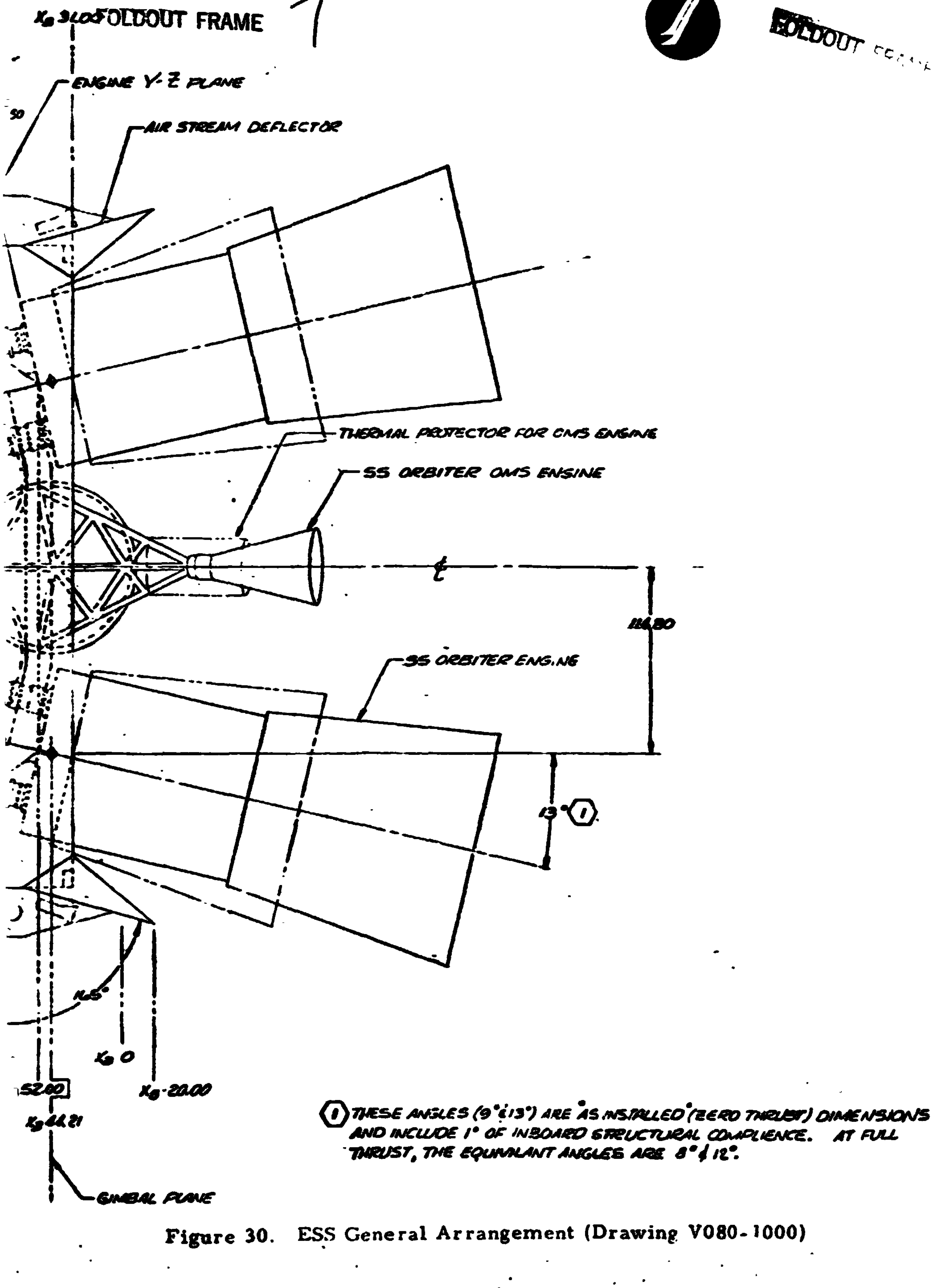
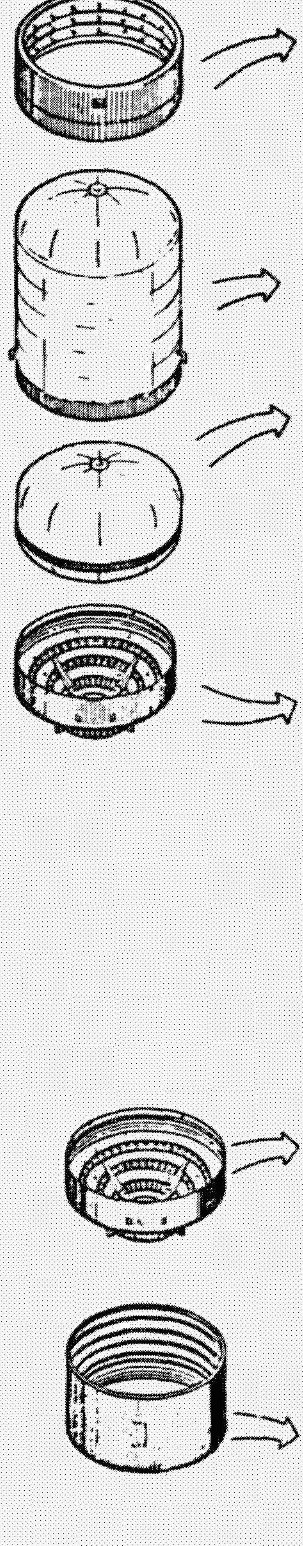


Figure 30. ESS General Arrangement (Drawing V080-1000)



STRUCTURAL ASSEMBLY	REQUIRED MODIFICATIONS
FORWARD SKIRT	A. FORWARD BOOSTER ATTACH FRAME (REPLACES GENERAL STABILITY FRAME) B. SKIN THICKNESS INCREASED TO 0.10 IN. (INTERMEDIATE STRINGERS DELETED) C. SMALL STRINGER THICKNESS INCREASE D. FORWARD ATTACH FITTING SUPPORTS
LH_2 TANK	A. BOSS PATTERN IN SIDEWALL FOR EROSION BARRIER INSTALLATION B. TWO FEED-LINE ELBOWS FOR ORBITER ENGINE (CYLINDER NO. 5 DELETED)
LO_2 TANK	A. SUMP FOR TWO ORBITER ENGINE FEED LINES
AFT SKIRT	A. AFT BOOSTER ATTACHMENT FRAME (REPLACES GENERAL STABILITY FRAME) (STATION 41) B. SKIN DOUBLER AND STRINGER REINFORCEMENT FOR BOOSTER ATTACH LOAD EFFECTS C. AFT BOOSTER ATTACHMENT FITTINGS D. LENGTH ~ FROM 87 INCHES FOR S-II TO 252 FOR ESS E. THRUST STRUCTURE ATTACH FRAME AT STATION 174.5 F. FRAME AT STATION 223 CHANGED TO STABILITY FRAME AND MOVED TO STATION 206.5 G. TWO FEED-LINE CUTOUTS H. ATTITUDE CONTROL SUPPORTS I. FRAME REINFORCEMENT (SHEAR DISTRIBUTION) J. FAIRINGS AT AFT END TO PROTECT ORBITER ENGINES FROM AERO SHEAR K. FRAME AT STATION 240 MOVED TO STATION 238 L. TWO ADDITIONAL GENERAL STABILITY FRAMES (STATIONS 127 AND 79) M. ATTACHMENT FOR DOCKING ADAPTER SUPPORT STRUCTURE
THRUST STRUCTURE	ALL NEW STRUCTURE INCORPORATING: A. ATTACHMENT FOR TWO SS ORBITER ENGINES B. 125.5 INCH HIGH CONICAL FRUSTUM (S-II IS 111 IN.) C. ATTACHMENT FOR TWO SS ORBITER OMS ENGINES D. REVISED STRINGER EXTRUSION SECTIONS AND SKIN THICKNESSES E. SUPPORTS FOR OMS PROPELLANT CONTAINERS F. SUPPORTS FOR ELECTRICAL EQUIPMENT
INTERSTAGE	NO INTERSTAGE REQUIRED

Figure 31. Summary of Major S-II Structural Modifications

A new aluminum thrust structure similar in structural configuration to that on the S-II is employed to support the two main and two orbit maneuvering system engines. The main propulsion engines are placed so that a central neuter docking core can be added for expansion of the ESS basic mission to the chemical interorbital shuttle mission.

Propulsion

The main propulsion system consists of two shuttle orbiter retractable nozzle rocket engines, developing 632,000 pounds of thrust each. Retracted within the protective area of the aft skirt airstream deflectors for aerodynamic protection during launch, the nozzles are extended shortly before ESS engine start. Propellants are delivered in a ratio of six to one through vacuum-jacketed lines. Main engine ignition, propellant delivery, mixture ratio, and shut-down are controlled by a digital computer mounted on the engine assembly. Thrust vector control is provided by engine gimbaling up to ±7 degrees in a square pattern. An independent hydraulic system is installed at each main propulsion engine to provide the forces to position and gimbal the engines in response to vehicle flight control commands. Each system consists of two linear-acting actuators: an S-II/J-2-type engine-driven pump and an S-II-type accumulator/reservoir/manifold assembly (ARMA). The engine-driven hydraulic pump system discussed here affects the shuttle engine ICD 13M15000B, since the shuttle orbiter engine does not currently have an accessory drive shaft. If this capability is not incorporated, an alternate hydraulic system using a pneumatic-driven hydraulic pump would be utilized. Pneumatic power would be taken from a tap on the stage side of the LH_2 tank pressurization line.

A majority of the S-II J-2 engine propulsion system components and/or complete systems are compatible with the shuttle orbiter engines, as shown in Table 6.

The main propulsion engines will be recovered for reuse. Attachments utilizing ordnance-actuated separable nuts for the engine and its servicing lines are used to permit separation of the engines from the stage for return to earth by the space shuttle orbiter.

To provide a safe environment for orbiter docking to recover hardware, the residual propellants in the main tanks will be sequentially dumped through the engines subsequent to velocity cutoff, by opening the engine propellant valves—LO_2 first, then LH_2. Following propellant dumping, the main tanks will be safed by actuating redundant ordnance vent valves mounted on each propellant tank. A nonpropulsive manifold is provided for each tank safing vent. This safing system is similar to that being developed for use on the S-II-13 stage, now designated to place the Skylab into earth orbit.

Table 6. S-II-15 ESS Commonality Assessment of Mechanical Systems

S-II System	ESS Configuration
Fill and Drain	S-II system
Propellant Feed	New System - 13-in. lines
Recirculation	S-II LH_2 recirculating pumps not used. Use valves, some recirculating lines, and most helium injection components.
Pressurization	S-II system (minor mods)
Vent	S-II system
Engine Servicing	Uses some S-II components, primarily disconnects
Valve Actuation	S-II system (minor mods)
Thrust Vector Control	New system
Propulsion Tank Safing	S-II system
Auxiliary Propulsion	New system

Propulsion beyond the initial orbit established with the main engines is accomplished with two shuttle-developed orbital maneuvering system engines of 10,000 pounds' thrust each. Mounted on the main propulsion thrust structure, they provide power for circularizing orbits, establishing new orbits, and performing rendezvous and deorbit maneuvers. Thrust vector control is provided by engine gimbaling up to ±6 degrees in a square pattern. Attitude control during nonpropulsion modes is achieved by 14 shuttle orbiter-developed thrusters, which provide precision stabilization of pitch, roll, and yaw. The orbital maneuvering system and the attitude control propulsion system (ACPS), jointly referred to as the auxiliary propulsion system (APS), draw their propellants (liquid hydrogen and liquid oxygen) from independent common tankage installed in the aft skirt section of the vehicle.

Avionics

Electrical power for the ESS systems is supplied by seventeen 28-volt batteries installed above the thrust structure in the aft skirt. Nine batteries, in groups of three, provide primary 28-volt dc power via three central main dc busses. Redundancy permits failure of any three batteries, one per group or one group, with the remaining batteries capable of providing the total electrical power required for the ESS 24-hour mission. Primary

115/200 volt, three-phase 400-Hz ac power is supplied by eight 28-volt batteries, in groups of two, and four 56-volt inverters. The output of the inverters is connected through a transformer to provde the ac power. Any two batteries have the capacity to handle the total peak load for one main engine. Each engine is connected to two ac power sources.

The integrated avionics system, Figure 32, supplies the central control for all ESS flight systems. Because of this comprehensive control, exercised by a central data and central management computer, the total avionics system encompasses a number of elements formerly treated as separate electrical and electronic subsystems. The major subsystems, which are monitored and controlled by the data and control management system (DCM), are guidance, navigation and control, communications, and power distribution and control. The DCM system also provides comprehensive on-board checkout, fault isolation, and redundancy management for the total vehicle (avionics and nonavionics systems) to the extent required to provide a fail-operational/fail-safe vehicle configuration.

The DCM computer receives data inputs from the ground, the booster, and on-board sensors and subsystems via a data bus. Coordinated control outputs, based on stored software programs, are distributed appropriately through the data bus to all flight systems.

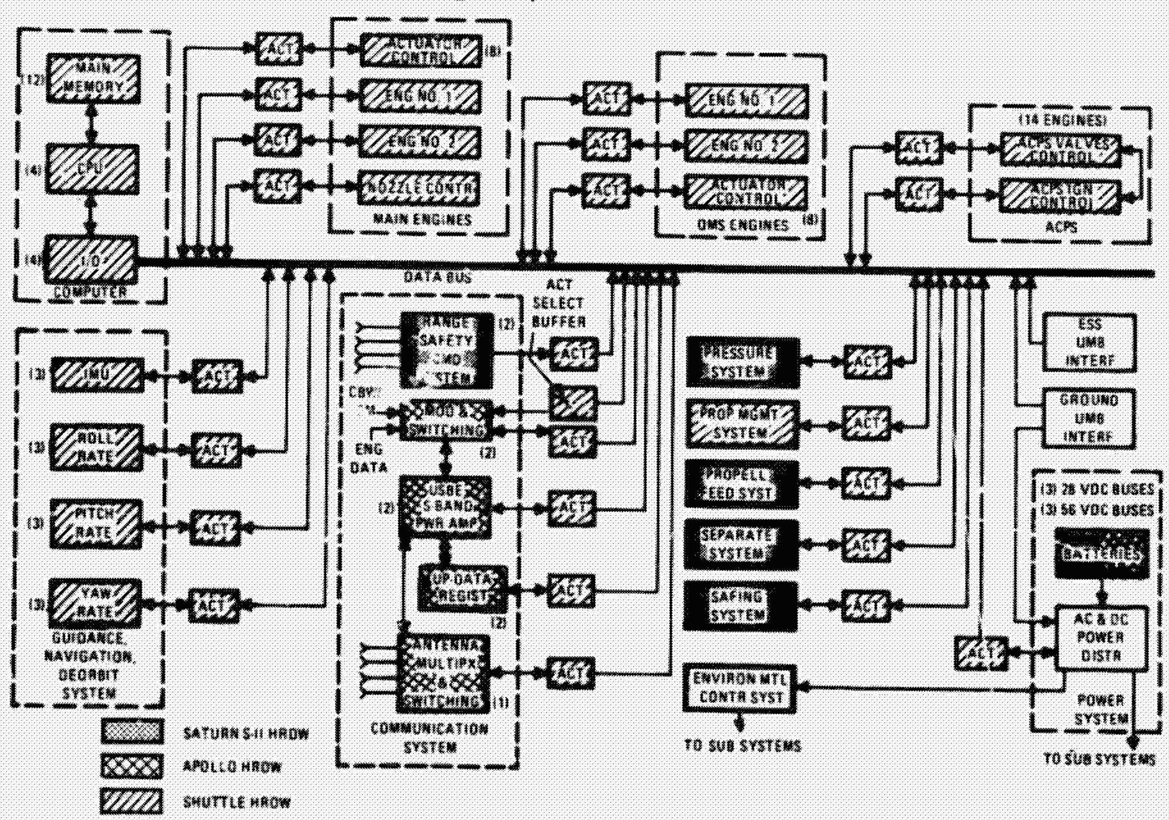


Figure 32. Integrated Avionics System

The guidance, navigation, and control subsystem, in conjunction with interfacing subsystem elements and ground and/or satellite tracking aids, provides the capability to determine the position, velocity, and inertial attitude of the ESS. It also provides attitude stabilization and control of the ESS from booster separation through ascent, on-orbit operations, and deorbit. This includes thrusting modes (main propulsion and OMS velocity changes) and nonthrusting modes (angular maneuvers and attitude holds using ACPS). Guidance and navigation parameters are derived from an inertial measurements unit (IMU) with no on-board attitude reference up-data capability. State vector updates are achieved by ground or relay satellite tracking and entered via uplink and the DCM. Separate body-mounted rate sensors are utilized for stability augmentation.

The ESS communications subsystem provides the capability of transmitting and receiving all RF information necessary to accomplish the ESS mission, by providing telemetry data, ranging data, and receiving up-data, range safety, and propellant dispersion commands.

The data subsystem is similar to the data system developed for the Apollo program, which provides the ability to format up-data for acquisition by the data bus, condition data bus signals suitable for modulation of the S-band transmitters, transmit engine and constant bandwidth/FM data, and select the redundant transponder and the required modulation mode for the mission phase. The data subsystem provides the ability to receive up-data from the Manned Space Flight Network (MSFN) or tracking and data relay satellites (TDRS), receive and provide coherent pseudorandom noise (PRN), and doppler tracking and ranging data, and transmit the telemetry signals to MSFN either directly or via the TDRS. The range safety and propellant dispersion equipment will be the same as that used on the Saturn S-II, which provides a reliable means of terminating the vehicle flight by up-link command in the event of deviation from the preplanned trajectory.

The removal and reuse of specific costly avionics equipment (IMU's and computers with main memory units) is proposed for cost-effectiveness. Four separate equipment containers will be separated from the stage by severing the attach brackets with exploding bridge wire-initiated linear-shaped charges. Spring-loaded separation-type connectors will be disconnected upon severing of the container attach brackets. A separate deorbit subsystem utilizing gyros, accelerometers, an up-data decoder, sequencer, and electronics will be used to deorbit the spent ESS after high-value component removal.

ESS Ground Support Equipment

As noted previously, the ESS is a modified Saturn second stage incorporating shuttle-developed propulsion and avionics elements. Maximum use will be made of existing S-II and associated shuttle ground support equipment. Existing S-II handling and auxiliary equipment will be adapted to provide transportation and handling of the ESS stage and handling, installation, and removal of stage parts and components. Equipment developed for servicing and checkout of the shuttle propulsion and avionics systems will be utilized on the ESS program. Some of this equipment may be modifications of existing Saturn S-II GSE.

BOOSTER VEHICLE MODIFICATION

The booster described at the end of the space shuttle Phase B study is almost identical to the booster utilized throughout the Phase B ESS study. The booster is a 268.5-foot, approximately four-million-pound, delta-wing vehicle equipped with 12 rocket engines for launch and 12 air-breathing turbofan engines for atmospheric cruise back to the launch site.

Manned by a commander and pilot, the vehicle is aerodynamically controlled with a pair of movable canards located somewhat forward of center and with conventional elevons and rudder on the trailing edges of the wing and vertical stabilizer. Attitude control above the atmosphere is maintained with a system of rocket thrusters. Landings are made on a typical large airport runway, using aircraft-type landing gear.

Reusable heat shielding is installed over all external surfaces to resist the high temperatures encountered during boost and reentry, while an environmental control system and appropriate insulation are employed to regulate internal temperatures.

The general arrangement and the various features of the selected booster are described in the Space Shuttle Phase B Final Report, SD 71-114-1 (Volume I, Executive Summary) and other volumes. Very briefly, the booster fuselage is primarily liquid oxygen and liquid hydrogen tankage. The liquid oxygen tank is located forward, immediately behind the crew compartment, and contains 305,000 gallons. A separate tank located behind the oxygen tank holds 880,000 gallons of liquid hydrogen. It is 33 feet in diameter.

The overall dimensions of the booster are illustrated in Figure 33, which shows the relationship of the orbiter/booster attachment points to the booster body. The attachment system also serves as the separation mechanism at staging.

All of the booster subsystems can be used with the ESS system with the exception of the orbiter separation system described above. The fixed platform and separation system for ESS mounting and separation are shown in Figure 34. This platform is mounted between the attachment points shown in Figure 33.

Several modifications have been made to the booster to accommodate the entire spectrum of loading conditions imposed by the three selected payloads, which are representative of the entire ESS payload spectrum. The acceleration load produced by the MDAC space station imposes a larger aft compressive load than does the orbiter, even using maximum permissible throttling consistent with payload requirements. This is caused by the greater distance from the top of the booster body to the center of gravity of the ESS than to the center of gravity of the orbiter. This greater offset tends to cause greater aft compressive loads. The side-wind load on the forward attachment mechanism, in a gust condition, is somewhat greater for the nuclear stage and the space station than for the orbiter. Accounting for these two load conditions imposes a flight load penalty in the booster's structure to accommodate all specified ESS payloads of approximately 1290 pounds. Ground-wind conditions existing at the launch site at KSC also must be considered. The loading arrangement, orientation of the booster, aerodynamic configuration for each of the payloads, and the wind direction at the launch pad have been analyzed. To account for this spectrum of conditions, a structural weight penalty in the aft region of the booster of 1890 pounds has been estimated. With these very small percentage weight changes to the reusable booster, empty weight of which is more than 600,000 pounds, accommodation of the various payloads is accomplished.

Minor changes in booster operations are needed to accommodate ESS payloads. Since only two vehicles per year are now projected for the ESS program, very little interference or impact to the on-going shuttle operations is anticipated.

Logically, the requirements for the ESS could be considered simultaneously with requirements for the orbiter in establishing design criteria for the reusable booster. With such a parallel approach, the impact on the booster to accommodate the ESS vehicle will diminish to a very small consideration in such an overall development.

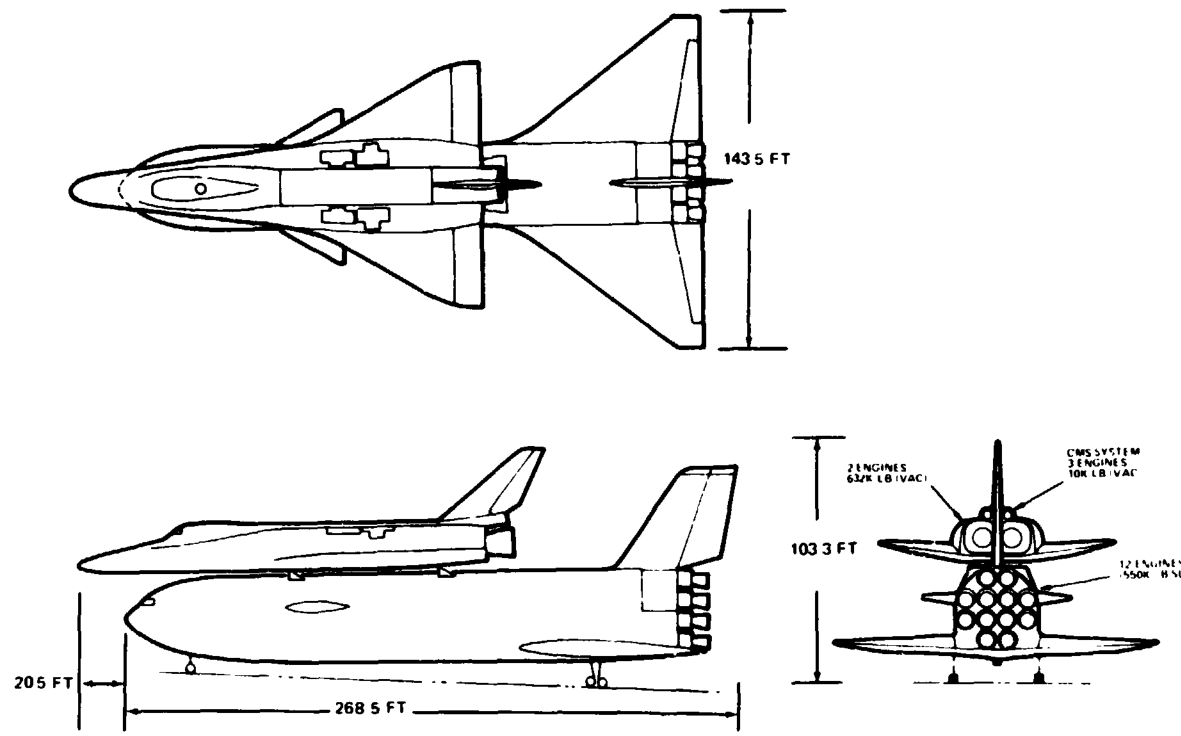


Figure 33. Booster/Orbiter Attachment Relationship

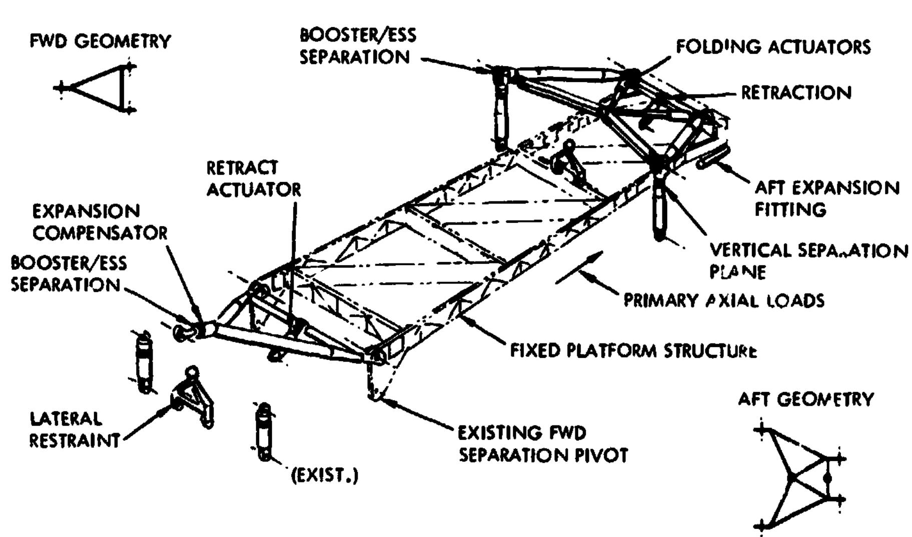


Figure 34. Fixed-Platform Linkage Concept—Booster/ESS Separation

PROGRAM COST AND SCHEDULE ESTIMATES

Effort was directed during the Phase B study to establish program costs for the ESS system to meet the requirement for two ESS flights per year for a period of 10 years, with the first flight in the last half of calendar year 1979. Schedules required to mesh the ESS program with the space shuttle schedule were established. Major requirements and implementation approaches for engineering, facilities, manufacturing, testing, operations, maintenance, logistics, and management were covered. Schedules and costs were estimated and include the effects of these program elements. Subsystem trades for the ESS, along with ground systems operations, were conducted on the basis of a technique featuring cost in design.

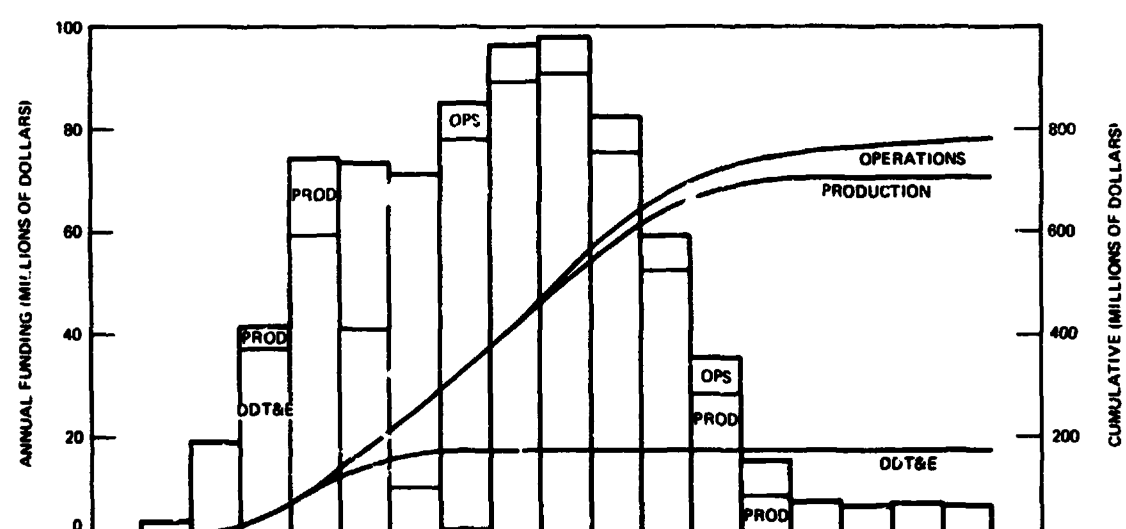
The total cost for developing and modifying the S-II to serve as an expendable second stage and modifying the shuttle booster vehicles for conducting an operational program through 1989 was estimated at $781.5 million. The recurring cost portion of this program was estimated at $609.3 million (see Table 7). The shuttle operational fleet was assumed to consist of 4 boosters and 5 orbiters. The 20 ESS vehicles supplement that shuttle fleet. Excluded from this cost estimate are the operational facilities costs and the main shuttle orbiter engine development and production costs.

Although ESS development would not require Phase C go-ahead simultaneously with the shuttle program, an ESS Phase C go-ahead has been assumed for March 1, 1972, to ensure maximum compatibility and concurrent consideration of requirements. A timed-phased funding plan for the 17-year period beginning on that date was prepared. This funding requirement estimate specifies a very small effort in GFY 1972. A moderate increase over the next nine years is postulated (Figure 35), building to a peak annual funding of $97.7 million in GFY 1981, and declining over the next eight years, with an average annual funding of less than $44 million through GFY 1989. The NASA Phase C/D work breakdown structure was expanded during Phase B to identify the units of work required for the ESS system program for the entire Phase C/D period. The cost model designed for this work breakdown structure is based both on the space shuttle computerized cost model and the S-II launch vehicle program cost model related to the S-II. The Phase C/D cost estimate for the ESS is projected by a parametric pricing technique based on historical cost data for the S-II and similar programs. For those components of the ESS derived from the orbiter vehicle, the pricing technique utilized for the shuttle applies. Vendor quotes for such shuttle components have been utilized for such components in the same

Table 7. Total ESS/Reusable Booster Cost Estimate

WBS Level-3 Elements	Cost ($ millions)*			
	Development	Production	Operations	Total Program
1.0 ESS	132.3	513.3	0	645.6
2.0 Main Engines	0**	0**	0**	0**
3.0 Booster Modification	8.5	0.5	0	9.0
4.0 Flight Test	0	0	0	0
5.0 Operations	0	0	74.8	74.8
6.0 Mgmt and Integ	4.0	12.5	1.8	18.3
7.0 Sep and Support Structure	27.4	6.4	0	[illegible]. 8
Total Cost	172.2	532.7	76.6	781.5

*Excluded from the cost estimates are main propulsion engines, payload modules, mission planning and simulation, operational facilities, total program management, and contractor's fees.
**Government-furnished equipment.



GFY	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
ANNUAL	0.3	3.4	19.0	41.7	74.1	73.3	71.0	85.0	96.1	97.7	82.2	59.1	35.3	15.2	7.3	6.9	7.0	6.9	
ESS	0.1	0.5	9.8	29.0	63.9	64.7	65.6	76.1	87.0	88.5	73.4	51.0	27.6	8.1	0.3				
RSB		0.5	2.7	4.0	1.6	0.1													
OPS								6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	
M&I		0.1	0.2	0.9	2.0	1.7	1.5	2.1	2.3	2.4	2.0	1.3	0.9	0.3	0.2	0.1	0.2	0.1	
SEP	0.1	2.3	6.3	7.8	6.6	6.8	3.9												

Figure 35. Total ESS/Reusable Booster Program Funding Requirement Estimate

manner as for the shuttle. The costing techniques for the shuttle are fully explained in Program Cost and Schedules (Phase B Space Shuttle Study), SD 71-107, and for the ESS/RSB in Volume XI of this report. The Phase C/D master program schedule for the ESS system establishes specific dates for key program events as required to develop the reusable booster and to meet the first ESS flight date in the last half of calendar year 1979. Cost monitoring of the development schedule for the shuttle Phase C/D is planned for the ESS program to assure system compatibility.

The Phase C/D master program summary schedule (Figure 36) outlines key milestones for development of the ESS and for modifications to the reusable space shuttle booster. No flight test vehicle of the ESS is shown. It is expected that the confirmation in flight of the ESS will be accomplished during the first operational flight. Program audits and standard design reviews will be conducted periodically throughout the ESS program by the contractor, with monitoring by NASA.

No significant technical problems are anticipated in the development of the ESS system. A new thrust structure will require the normal type of development and testing. The loads on the primary structure require confirmation. The insulation requires a thermal barrier not currently provided. Installation of the orbiter avionics elements requires verification although it is not expected to require major development. The primary booster loading of specific regions involves somewhat heavier bulkheads in two areas, with slightly increased skin thickness in the aft region. Also, development of a special fixed-platform attachment structure will augment the type of separation system used for the orbiter. Alteration of the booster control software is required for ESS flights, without modification of the flight control system hardware.

To minimize Phase C/D program costs, maximum integration of the ESS operation into the shuttle operation is assumed. These operations are described in considerable detail in other volumes of this report.

The actual construction of the ESS is assumed to be similar to that of the S-II. Further, it is assumed that delivery by water transportation to the Kennedy Space Center (KSC) will be accomplished. Main propulsive testing on the ESS will be performed in a manner similar to that recommended for the orbiter in the same facility. Wind tunnel tests, structural tests, and auxiliary propulsion system tests will be performed at Government facilities in a manner similar to that recommended for the shuttle. Tests of subsystems derived from shuttle developments will be performed in conjunction with tests for such subsystems in connection with the shuttle. The ESS program cost estimates are given in Table 8.

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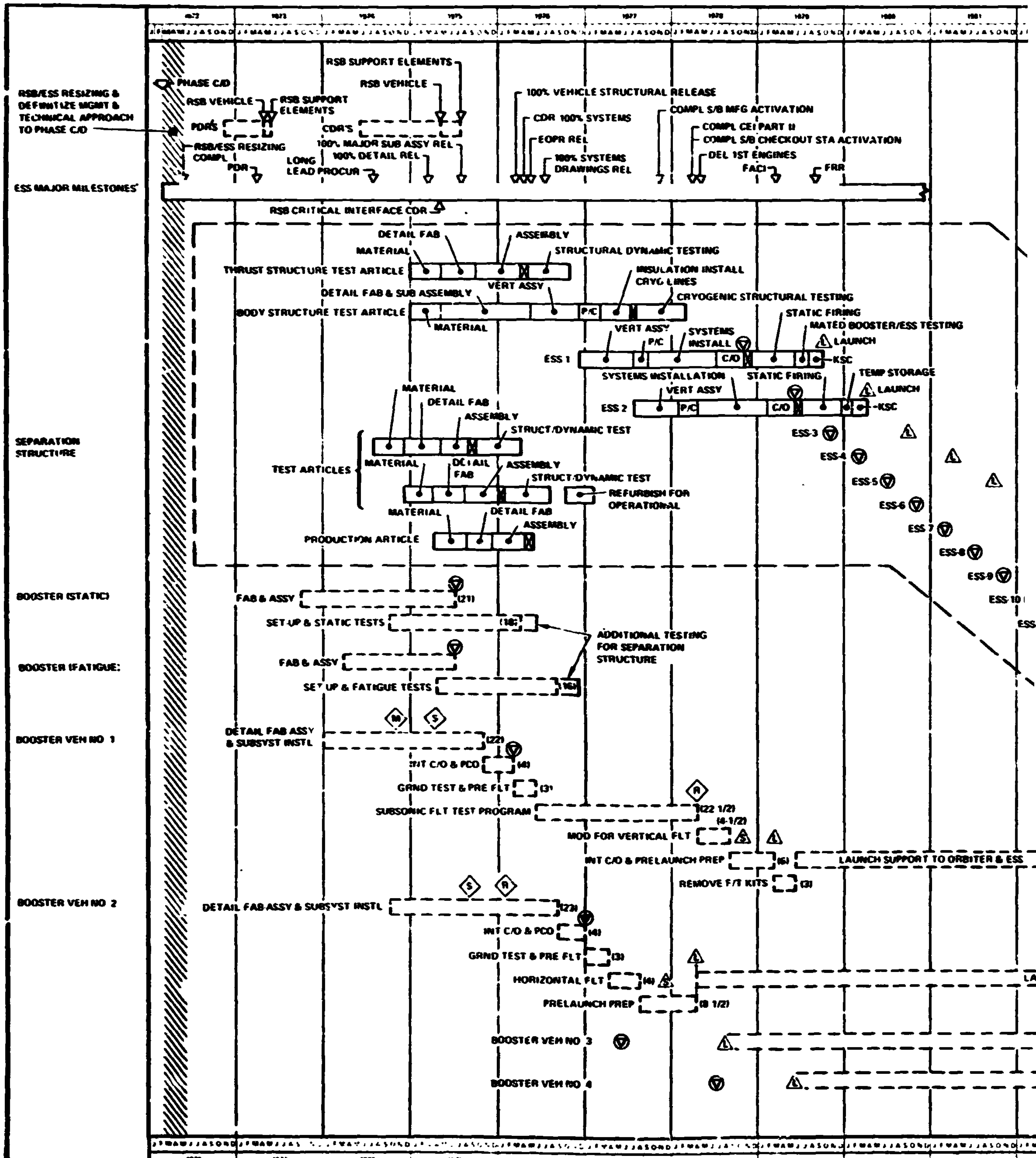

Figure 36.

FOLDOUT FRAME 2

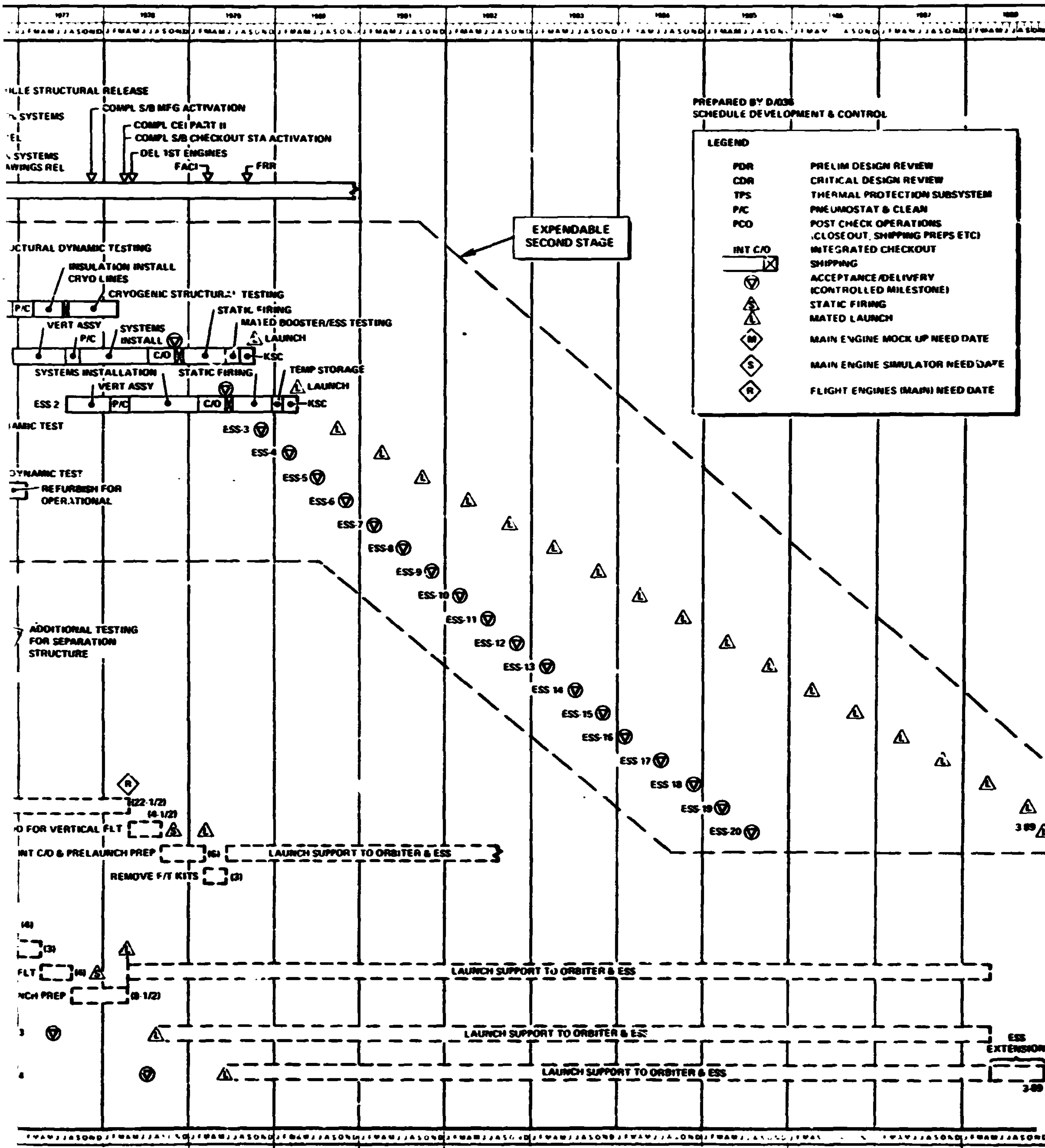

Figure 36. Phase C/D Master Program Schedule for ESS/Reusable Shuttle Booster

Table 8. ESS Program Cost Estimates

	Cost ($ millions)*			
		Recurring		
	Development	Production	Operations	Total
1.0 ESS (Total)	132.3	513.3	0	645.6
1.1 Structural Grp	27.0	211.0	0	238.0
1.2 Propulsion Grp	8.2	101.1	0	109.3
1.3 Avionics Grp	25.5	65.5	0	91.0
1.4 Veh Support Grp	7.4	23.6	0	31.0
1.5 Mech Subsys Grp	0	0	0	0
1.6 Veh Installation, Assy, and Checkout	6.8	34.4	0	41.2
1.7 Combined Subsystems Test	0	0	0	0
1.8 Systems Engrg and Integration	28.5	38.5	0	67.0
1.9 Facilities	4.0	0	0	4.0
1.10 Sys Support	33.0	21.6	0	54.6
1.11 Veh Management	1.9	4.8	0	6.7
1.12 Models and Mockups	0	0	0	0
1.13 Payload Integration	0	0	0	0
1.14 Transport and Delivery	0	12.8	0	12.8

*Excluded from the cost estimates are main propulsion engines, payload modules, mission planning and simulation, operational facilities, total program management, and contractor's fees.

The schedule estimate for the ESS program shows delivery of the first ESS to KSC in December 1978. The first two ESS vehicles will be static-fired at KSC on a noninterference basis with the shuttle program.

The booster program cost estimate for the ESS system includes the cost of modifications to the shuttle baseline booster. Proof checking of the separation system is recommended as a supplementary test to those for the shuttle separation system. Full-scale vibration tests will be conducted at KSC for each of the ESS-payload combinations selected for flight. These facilities selections are intended to make maximum use of shuttle planning and to impose minimum incremental tests.

The operations cost estimate considers tasks essential for flying the ESS system. These tasks include supplying propellant and gas, training, vehicle and equipment maintenance, and facilities operations. Excluded from these costs are mission planning and simulation, operational facilities, payloads, and the main propulsion system engines.

The management cost estimate is based on the assumption that NR would manage the system, but not the total program. Through planning, cost estimating, and scheduling efforts, a cost-effective supplementary system to the space shuttle program has been defined. For selected missions, the ESS system clearly will provide flexibility and augment the shuttle system.

Based on the above data for recurring cost only (20-vehicle program), the cost per flight is $30.5 million. For a payload of 183,000 pounds (delivered to the design reference orbit: 270 nautical miles, 55-degree inclination), the cost per pound of payload is $167. Including the recurring costs for the initial purchase of the engines (three vehicle sets) and the cost of operational facilities, the comparable cost-effectiveness figure is $173 per pound.